EUI WORKING PAPERS IN ECONOMICS

EUI Working Paper ECO No. 95/26

Cooperative R&D Versus R&D-Subsidies: Cournot and Bertrand Duopolies

JEROEN HINLOOPEN

European University Institute, Florence

EUROPEAN UNIVERSITY INSTITUTE, FLORENCE

ECONOMICS DEPARTMENT

EUI Working Paper ECO No. 95/26

Cooperative R&D Versus R&D-Subsidies: Cournot and Bertrand Duopolies

JEROEN HINLOOPEN

BADIA FIESOLANA, SAN DOMENICO (FI)

Printed in Italy in July 1995
European University Institute
Badia Fiesolana
I – 50016 San Domenico (FI)
Italy

Cooperative R&D versus R&D-subsidies: Cournot and Bertrand Duopolies

JEROEN HINLOOPEN*

European University Institute
Department of Economics
I-50016 San Domenico di Fiesole (FI)
Italy

May 1995

Abstract

Comparing the effect on private R&D investments of allowing firms to collude in R&D with that of providing R&D-subsidies (for which firms are taxed in the product market) reveals that in most cases, both under Cournot and Bertrand competition the latter policy is more effective than the former in promoting R&D activity. Analyzing the implementation of both policies *simultaneously* reveals that (i) allowing firms to collude in R&D is redundant and (ii) firms should only be encouraged to share their (independent) research outcomes (i.e. form RJVs) and this agreement should be subsidized accordingly. Abandoning antitrust legislation concerning private R&D is therefore not supported by the analysis presented here.

Keywords: R&D-subsidies, cooperation in R&D, spillovers.

JEL Classification: L43, O32.

* I would like to thank Stephen Martin for helpful comments and stimulating discussions. Of course, any error is mine.

1. INTRODUCTION

Policy makers face the problem of narrowing the fundamental gap between social and private incentives to invest in research and development (R&D).[1] One possibility to trigger private R&D activity is to provide direct R&D-subsidies, or to grant innovating firms tax credits. Another option is to allow firms to cooperate in R&D, a policy which recently has been implemented in Europe, the United States and Japan.[2] Especially this latter policy has received substantial attention in recent economic literature.[3]

Cooperation among firms can range from occasional information sharing to maximizing joint profits. To avoid confusion as to what is meant by cooperation in R&D we adopt the definitions given by Kamien *et al.* (1992). They distinguish three types of R&D collusive agreements depending on the extent to which firms exchange innovative information and whether or not R&D investments are unilaterally or jointly set. First there are 'R&D-cartels': "agreements to coordinate R&D activities so as to maximize the sum of overall profits" (p. 1294). This contract does not imply that participating firms share the outcomes of their R&D efforts, which means that technological spillovers (that is, the ability of rivals to benefit from each others' R&D efforts at little or no cost) are not completely internalized. If on the other hand competitors agree to exchange *only* innovate information they participate in a research joint venture (RJV): "agreements in which firms decide unilaterally on their R&D investments but the results of their R&D are fully shared" (p.1294).[4] Within RJVs techno-

---

[1] Katz and Ordover (1990) identify several forces which create the discrepancy between social and private incentives to conduct R&D. Depending on the industry, Bernstein and Nadri (1988) estimate the social rate of return to R&D capital to be 0.1 to 10 times the private rate of return (see also Mansfield et al.(1977)).

[2] In Europe, the European Commission granted in its Regulation 418/85 a thirteen-year block exemption under Article 85 para.3 to collusion in R&D. In the United States some cooperation between innovating firms is allowed under the National Cooperative Research Act of 1984 and the National Cooperative Production Amendments of 1993. Japanese corporate law also allows firms to cooperate in R&D. For an elaborate comparison between Europe, the U.S. and Japan on this issue see Martin (1995).

[3] See a.o. Jacquemin (1988), Marjit (1991), Suzumura (1992), Choi (1993), Geroski (1993), Kamien and Zang (1993), Martin (1994a), Simpson and Vonortas (1994), Vonortas (1994) and Ziss (1994) and the other references in this paper.

[4] Kamien et al. (1992) do not give precisely this definition of a RJV but it can be inferred from their definition of *R&D competition* and their description of a RJV.

logical spillovers are completely internalized whereas in R&D-cartels there is still room for duplication of research. Note that RJVs do not entail cooperation in R&D to the extent that R&D investments are coordinated. Rather they indicate the sharing of results of *independent* R&D efforts. Finally, firms are engaged in a 'RJV-cartel' if they agree to fully share the results of their R&D *and* to coordinate their R&D activities in order to maximize the sum of overall profits.[5]

On a firm level the benefits of sharing innovative information and/or colluding in R&D abound. Internalizing the negative externalities associated with R&D spillovers increases the appropriability of R&D investments. Further, synergetic effects may accelerate the speed of innovation (enabling colluding firms to start recovering their R&D investment at an earlier date) and widen the scope of research projects which are feasible and potentially profitable. This enlargement in range of potential R&D projects is particularly true if R&D is characterized by economies of scale or scope. Finally, forming RJV-cartels diminishes wasteful duplication in research, and risks and fixed (sunk) costs are shared (all leading to less overall spending to achieve a given innovation).

On the other hand there are also disadvantages attached to participating in a joint R&D project. Partner selection is difficult and the R&D venture can collapse if participating firms have different objectives. A single (big) R&D venture might be difficult to manage compared to several independent (and smaller) projects. Cooperative R&D may push participants' ideas in the same direction (dead-end research), while independent R&D might yield a wider range of inventions. Members may be tempted to free-ride on each other, and successful joint innovations may disproportionately strengthen other members in the product market.

From society's point of view there are also arguments in favour of allowing firms to cooperate in R&D and/or to share their R&D-results. Innovations are better disseminated due to the internalization of technological spillovers.[6] This in turn leads to an increased rivalry concerning the use of the new technology (among members) and prevents monopolizing the rents of

[5] In the sequel, whenever we mention cooperation or collusion in R&D we implicitly refer to R&D-cartels except when otherwise indicated.

[6] Allowing firms to cooperate in R&D is clearly preferable to tightening intellectual property rights. The latter policy does increase the appropriability of R&D investments but diminishes the dissemination of technical know-how. Also the effectiveness of granting more elaborate patents may be questioned (see Mansfield (1985)).

inventions. Also, if innovative information is fully shared new discoveries are more efficient because more firms benefit from a single invention. Further, since appropriability of R&D investments is improved and because the cost of R&D are lowered through cooperation (due to risk sharing and the sharing of sunk cost), private R&D investments will increase.

However, there are potential threats. Since successful R&D projects can lower margins in the product market, colluding firms may decide to do less R&D compared to independent research. This not only reduces competition in the R&D stage, but also in the product stage because fewer new products are introduced. In particular, a dominant firm may slow down the pace of innovation preserving its position in the product market. Also, since duplication of research might be avoided (depending on the type of cooperative R&D agreement) and because of synergetic effects, an agreement to collude in R&D may give members of the venture a disproportionate advantage compared to nonparticipants. Increased entry barriers will then lead to socially undesirable market power for members of the venture. Probably the biggest danger is, however, that colluding firms are tempted to extend the R&D-collusion agreement to the product market to gain additional market power (for example, side-payments to preserve a production-cartel are more easily made).

On the whole, it is difficult to determine whether or not relaxing antitrust laws with respect to private R&D is socially desirable.[7] Subsidizing R&D is the leading alternative to enhance private R&D investments.[8] Of course, this policy also has its merits and costs. It restores (or at least stimulates) the incentives to conduct R&D. Entry barriers will be lowered due to lower (marginal and/or fixed) cost of R&D investments. This in turn will trigger competition both in the R&D stage and the product market (the latter because more new products are introduced). And, above all, the danger that firms will illegally extend cooperative R&D agreements is absent.

[7] For instance, Katz and Ordover (1990) claim that "the United States has pursued mistaken and outdated antitrust policies that limit the ability of U.S. firms to compete in global high-technology markets", whereas Shapiro and Willig (1990) conclude that "there is precious little evidence that overly strict antitrust policies have stifled innovation by American firms or hindered American firms from competing abroad".

[8] See Spencer and Brander (1983), Spence (1984), Bagwell and Staiger (1994) and Hinloopen (1994).

On the other hand, R&D-subsidies do not stimulate dissemination of technological knowledge[9] and firms may deceive the authorities to receive the subsidy (e.g. labelling to much personnel as researcher). Also, R&D-subsidies may even further distort market outcomes (possibly leading to socially excessive R&D-investments) and ex ante it is not certain that a government will only subsidize successful research projects.[10] Finally, taxes to raise the R&D-subsidy have distortionary effects and may be politically unfeasible.

Although the literature on R&D-cooperation and subsidizing R&D is substantial, no analyses consider *both policies simultaneously*. This paper is an attempt to fill this gap and generalizes Hinloopen (1994). In order to keep results as tractable as possible we build on the stylized models of Dixit (1979) and d'Aspremont and Jacquemin (1988). The latter have developed a two-stage model, describing a duopoly for homogeneous products with explicit technological spillovers, to analyze collusive R&D. In the first stage firms determine their R&D investment. Given this investment, output is set in the second stage (that is, firms act as Cournot competitors). Within this framework three different scenarios are considered, so that the effects of partial and full collusion on market behaviour can be examined: first, no cooperation in either the first or the second stage; second, cooperation in R&D and competition in output; third, cooperation in both the first and the second stage. To allow for products to be differentiated and to also consider Bertrand competition we combine d'Aspremont and Jacquemin's model with that of Dixit (1979). He provides us with a representative consumer's utility function from which demand curves for differentiated products can be derived. Finally, to analyze the effects of authorities allowing firms to cooperate in R&D *and/or* providing R&D-subsidies, we also introduce an active government. Prior to the R&D-setting stage this government subsidizes R&D in order to maximize social welfare. Following Spencer and Brander (1983) we assume that firms pay a lump-sum tax in the production stage in order to finance the R&D-subsidy. With this framework we are able to compare the two policy options both under Cournot

---

[9] Katz and Ordover (1990) conclude that therefore R&D-subsidies are ineffective in markets where technological spillovers are low. However, to the extent that R&D-subsidies increase private R&D investment (independent of the size of technological spillovers) this conclusion is premature.

[10] If a government could tell in advance which project would be successful, many of the problems of R&D would go away. However, because a government does not have this knowledge it will have to subsidize some unsuccessful projects.

and Bertrand competition as well as to derive the optimal policy mix in terms of social welfare.

The main results of the analysis are that under both second stage Cournot and Bertrand competition: (i) a government can increase private R&D investments, output and social welfare, through R&D-subsidies, (ii) subsidizing non-collusive R&D optimally is more effective in raising R&D than permitting RJVs or R&D-cartels without subsidization (and in some cases also more effective than allowing for a non-subsidized RJV-cartel), (iii) subsidizing non-cooperative R&D or subsidizing R&D-cartels leads to the same market outcome (and social welfare)[11], that is, cooperation in R&D is redundant, and (iv) yet only RJVs should be encouraged and subsidized.

The organization of this paper is as follows. In the next section the synthesis of Dixit's (1979) model and that of d'Aspremont-Jacquemin (1988) is presented. Within this framework the three scenarios of d'Aspremont and Jacquemin are analyzed in Section 3. The subsequent section examines whether or not firms should be allowed to cooperate in R&D and/or to share their innovative information. Optimal R&D-subsidies for the three scenarios described above are derived in Section 5. In Section 6 the optimal 'policy mix' in terms of social welfare is presented. Several concluding remarks are made in the last section.

2. THE MODEL

The supply side of the economy consists of a monopolistic sector, in which two firms each produce one variety of a differentiated commodity (q_1 and q_2), and of a competitive sector which produces a *numeraire* good (q_0). In the monopolistic sector the marginal cost of production, A, is constant, but can be lowered if firms invest in R&D (that is, R&D is process innovating). The costs of R&D are quadratic, reflecting the diminishing returns to R&D. On the demand side there is a continuum of consumers of the same type. Each consumer's utility function is linear and separable in the *numeraire* good. This implies that the competitive sector imposes no income effects on the duopoly, allowing us to consider only a partial equilibrium analysis. The representative consumer maximizes (Dixit (1979))

[11] In case of maximal spillovers this result reads as "subsidising RJVs or subsidising RJV-cartels lead to the same market outcome (and social welfare)".

$$U(q_0,q_1,q_2)-\sum_{i=0}^{n}p_iq_i = q_0+U(q_1,q_2)-(q_0+\sum_{i=1}^{n}p_iq_i)$$
$$= a(q_1+q_2)-\frac{b}{2}(q_1^2+2\theta q_1q_2+q_2^2)-\sum_{i=1}^{2}p_iq_i, \tag{1}$$

where q_i, $i=1,2$, is firm i's production, and p_i the price it quotes. The parameter $\theta\in[0,1)$, indicates to what extend the two products are differentiated; if $\theta\approx 1$ products are homogeneous whilst products are perfectly differentiated (and independent) if $\theta=0$. The functional form of utility proposed in (1) leads to the following system of inverse demands

$$p_1 = a-bq_1-\theta bq_2,$$
$$p_2 = a-bq_2-\theta bq_1. \tag{2}$$

or, in direct rather than indirect form,

$$q_1 = \frac{1}{b(1+\theta)}[a-\frac{(p_1-\theta p_2)}{(1-\theta)}],$$
$$q_2 = \frac{1}{b(1+\theta)}[a-\frac{(p_2-\theta p_1)}{(1-\theta)}]. \tag{3}$$

For (3) to be well defined, products cannot be completely homogeneous. Whenever we refer to homogeneous products we implicitly assume that products are differentiated to an infinitesimal small extent, i.e. $\theta+\varepsilon=1$ where $\varepsilon\downarrow 0$.[12]

Given demand and cost structures outlined above, profits of a single firm can be summarized by

$$\pi_i(q_i,q_j,x_i,x_j) = p_iq_i-(A-x_i-\beta x_j)q_i-\gamma\frac{x_i^2}{2}, \quad i,j=1,2, \quad i\neq j, \tag{4}$$

where x_i is firm i's investment in R&D and where $\beta\in[0,1]$ measures the spillover effect. Following d'Aspremont and Jacquemin, henceforth DJ, we assume that $a,b>0$, $q_i+\theta q_j\leq a/b$ and $A\geq x_i+\beta x_j$.

[12] Strictly speaking we only have to make this refinement in case of Bertrand competition, since under Cournot competition the decision variable is output, implying that firms consider only inverse demand.

Welfare comparisons are based on the sum of producers' and consumers' surplus. In the context of differentiated products this measure deserves special attention.[13] Spence (1976) shows that for the type of model considered here in symmetric equilibrium (i.e. $x_i = x_j = x$, and $q_i = q_j = q$) total surplus ($T(n)$) is given by

$$T(n) = n\left(a - \frac{b(1+\theta(n-1))}{2}q\right)q,$$

where n is the number of firms. Social welfare for the model employed here thus equals[14]

$$\begin{aligned} W &= T(2) - 2(A-(1+\beta)x)q - \gamma x^2 \\ &= 2\left[(a-A)+(1+\beta)x - \frac{b(1+\theta)}{2}q\right]q - \gamma x^2. \end{aligned} \tag{5}$$

It is this expression we seek to maximize when providing R&D-subsidies for which firms are taxed in the output stage, supposing that firms' outputs and R&D-investments are the equilibrium outcomes of the appropriate market game.

3. COOPERATIVE AND NON-COOPERATIVE R&D: COURNOT AND BERTRAND

We proceed with solving the DJ games for the model presented in Section 2. Because products are allowed to be differentiated we will consider both Cournot and Bertrand competition.

3.1 NO COOPERATION IN EITHER R&D OR OUTPUT: COMPETITIVE R&D

Maximizing (4) with respect to q_i for $i=1,2$, conditional on R&D expenditures gives us the equilibrium quantity

$$q_i(x_i,x_j) = \frac{1}{b(4-\theta^2)}[(a-A)(2-\theta)+(2-\theta\beta)x_i+(2\beta-\theta)x_j], \tag{6}$$

[13] See Martin (1985) and the comment of Wildman (1984) on Scherer (1979).

[14] Notice also that $W = U(q,q) - 2(A-(1+\beta))q - \gamma x^2$.

for $i,j=1,2,\ i\neq j$. If on the other hand in the second stage firms compete in prices, (4) must be maximized with respect to p_i for $i=1,2$. Equilibrium prices thus derived equal

$$p_i = \frac{1}{4-\theta^2}[(2+\theta)(A+(1-\theta)a)-(2+\theta\beta)x_i-(2\beta+\theta)x_j], \tag{7}$$

for $i,j=1,2,\ i\neq j$. In the preceding stage, when firms determine their R&D investment, profits in case of Cournot or Bertrand competition can be written respectively as

$$\pi_i^C(x_i,x_j)=\frac{1}{b(4-\theta^2)^2}[(a-A)(2-\theta)+(2-\theta\beta)x_i+(2\beta-\theta)x_j]^2-\gamma\frac{x_i^2}{2}, \tag{8a}$$

$$\pi_i^B(x_i,x_j)=\frac{(1-\theta)}{b(1+\theta)(2-\theta)} \times [(a-A)-\frac{(2-\theta\beta-\theta^2)x_i+(2\beta-\theta-\theta^2\beta)x_j}{(1-\theta)(2+\theta)}]^2-\gamma\frac{x_i^2}{2}, \tag{8b}$$

for $i,j=1,2,\ i\neq j$. R&D-reaction functions follow from $\partial\pi_i(x_i,x_j)/\partial x_i=0$, for $i,j=1,2,\ i\neq j$, and are given by[15]

$$x_i^C(x_j^C) = \frac{2(a-A)(2-\theta)(2-\theta\beta)}{b\gamma(4-\theta^2)^2-2(2-\theta\beta)^2}+\frac{2(2-\theta\beta)(2\beta-\theta)}{b\gamma(4-\theta^2)^2-2(2-\theta\beta)^2}x_j^C,$$

$$x_i^B(x_j^B) = \frac{2(a-A)(1-\theta)(2+\theta)(2-\theta\beta-\theta^2)}{b\gamma(1-\theta^2)(4-\theta^2)^2-2(2-\theta\beta-\theta^2)^2} + \frac{2(2-\theta\beta-\theta^2)(2\beta-\theta-\theta^2\beta)}{b\gamma(1-\theta^2)(4-\theta^2)^2-2(2-\theta\beta-\theta^2)^2}x_j^B,$$

for $i,j=1,2,\ i\neq j$. From these we can derive the following stability conditions (see e.g. Henriques (1990))

[15] The second order condition for the Cournot case is that $2(2-\theta\beta)^2<b\gamma(4-\theta^2)^2$, while in case of Bertrand competition it must be that $2(2-\theta\beta-\theta^2)^2<b\gamma(1-\theta^2)(4-\theta^2)^2$.

$$|\partial x_i^C(x_j^C)/\partial x_j^C| < 1 \Leftrightarrow b\gamma(4-\theta^2)(2+\theta) > 2(2-\theta\beta)(1+\beta), \tag{9a}$$

$$|\partial x_i^B(x_j^B)/\partial x_j^B| < 1 \Leftrightarrow b\gamma(1+\theta)(2-\theta)(4-\theta^2) > 2(2-\theta\beta-\theta^2)(1+\beta). \tag{9b}$$

Equating the R&D-reaction functions finally leads to equilibrium R&D investments

$$x_I^C = \frac{2(a-A)(2-\theta\beta)}{b\gamma(2+\theta)(4-\theta^2)-2(2-\theta\beta)(1+\beta)}, \tag{10a}$$

$$x_I^B = \frac{2(a-A)(2-\theta\beta-\theta^2)}{b\gamma(1+\theta)(2-\theta)(4-\theta^2)-2(2-\theta\beta-\theta^2)(1+\beta)}. \tag{10b}$$

Notice that stability conditions (10) ensure that both in case of second stage Cournot and Bertrand competition R&D investments are positive.

3.2 COOPERATION IN R&D, COMPETITION IN OUTPUT: R&D-CARTEL

When firms cooperate in R&D but compete in the second stage, equilibrium quantities are still given by (6) if firms' decision variable is output, while equilibrium prices equal (7) if firms play the Bertrand game. In the second stage firms maximize joint profits ($i \neq j$)

$$\Pi^C(x_i,x_j) = \frac{1}{b(4-\theta^2)^2}\sum_{i=1}^{2}\{[(a-A)(2-\theta)+(2-\theta\beta)x_i+(2\beta-\theta)x_j]^2-\gamma\frac{x_i^2}{2}\},$$

$$\Pi^B(x_i,x_j) = \frac{(1-\theta)}{b(1+\theta)(2-\theta)}$$

$$\times\sum_{i=1}^{2}\{[(a-A)+\frac{(2-\theta\beta-\theta^2)x_i+(2\beta-\theta-\theta^2\beta)x_j}{(1-\theta)(2+\theta)}]^2-\gamma\frac{x_i^2}{2}\}.$$

The symmetric R&D levels which maximize joint Cournot or Bertrand (first-stage) profits are given by[16]

$$x_{II}^{C} = \frac{2(a-A)(1+\beta)}{b\gamma(2+\theta)^2-2(1+\beta)^2} \tag{11a}$$

and

$$x_{II}^{B} = \frac{2(a-A)(1-\theta)(1+\beta)}{b\gamma(1+\theta)(2-\theta)^2-2(1+\beta)^2(1-\theta)}, \tag{11b}$$

respectively.

Comparing (11) with (10) reveals that allowing firms to cooperate in R&D increases R&D investment if $\beta>\theta/2$ for the Cournot game and if $\beta>\theta/(2-\theta^2)$ when firms face Bertrand competition. Considering the Cournot case first, note that when products are homogeneous (i.e. $\theta=1$) "for large spillovers, that is, $\beta>0.5$, the level of R&D increases when firms cooperate in R&D" (DJ, p.1135). However, neglecting the fact that products are differentiated imposes too strict a condition on the size of technological spillovers for cooperation to increase R&D investment, since for differentiated products $\theta/2$ is *below* 0.5. If, for example, authorities have no or poor information on the extent to which products are differentiated and therefore assume θ to be uniformly distributed over the unit interval, then it can be expected that also for values of β between 0.25 and 0.5 cooperative R&D exceeds non-cooperative R&D, since the expected value of $\theta/2$ equals 0.25. If also the spillover effect is unknown to the government and therefore it also assumes β to be uniformly distributed over the unit interval, cooperation will lead to an increase in R&D expenditure with a probability of 75% (as opposed to 50% for homogeneous goods).[17] In the limiting case of completely differentiated products, cooperation in R&D always leads to more R&D investment.

If on the other hand firms are engaged in Bertrand competition, *competitive R&D investment always exceeds cooperative R&D investment if products are (almost) homogeneous*. That is, allowing firms to form an R&D-cartel leads to *less* overall R&D-investment. Restricting the analysis to Cournot competition, as is commonly done in the literature, can therefore lead to

---

[16] The second order condition is $2(2-\theta\beta)^2+2(2\beta-\theta)^2<b\gamma(4-\theta^2)^2$ under Cournot, and under Bertrand we impose that $(2-\theta\beta-\theta^2)^2+(2\beta-\theta-\theta^2\beta)^2<b\gamma(1-\theta^2)(4-\theta^2)^2/2$.

[17] $\int_0^1\int_{\theta/2}^1 d\beta\, d\theta=0.75$.

misleading conclusions as to the effect on private R&D investment of allowing firms to cooperate in R&D. Again, however, it is more realistic to assume products to be differentiated. In that case allowing firms to cooperate in R&D can trigger R&D activity. For instance, if it is held that the government is poorly informed about the degree of product differentiation and it consequently assumes this degree to be uniformly distributed over $[0,1]$, then the expected value of $\theta/(2-\theta^2)$ is $\ln(2)/2 \approx 0.35$. That is, cooperative R&D exceeds non-cooperative R&D whenever the spillover rate is above 35%. If the extent to which technological knowledge leaks out is also assumed to be uniformly distributed between 0 and 1, the probability that allowing firms to cooperate in R&D will increase R&D investment is 65%.[18] Finally, as in the case of second stage Cournot competition, cooperative R&D always exceeds competitive R&D when products are completely differentiated.

Before we proceed with analyzing the full cooperation case it is worthwhile to give some thoughts as to why cooperative R&D exceeds non-cooperative R&D only when spillovers are substantial (relative to the degree of product differentiation). A possible explanation lies in the interaction between synergy and technological spillovers. If spillovers are modest (i.e. $\beta<\theta/2$ or $\beta<\theta/(2-\theta^2)$, depending on the type of competition firms are engaged in), synergy from cooperation can be expected to be counterproductive. Cooperation in R&D will therefore induce firms to reduce R&D investment compared to competitive R&D efforts. On the other hand, if spillovers are substantial (i.e. $\beta>\theta/2$ or $\beta>\theta/(2-\theta^2)$), synergetic effects will contribute positively to the R&D-process (and because the collusive R&D investment is increasing in the spillover rate, synergy outweighs the disincentives of non-appropriability[19]). Moreover, in this case the appropriability of independent research is much less compared to the small spillover case. As a result, competitive R&D falls below collusive R&D.

3.3 COOPERATION IN BOTH R&D AND OUTPUT: MONOPOLY

If firms are allowed to collude both in the first and second stage of the production process they first maximize joint profits

---

[18] $\int_0^1 \int_{\theta/(2-\theta^2)}^1 d\beta\, d\theta = 1 - \ln(2)/2 \approx 0.65$.

[19] An appendix in which several partial derivatives are analyzed (including those appropriate here) is available from the author upon request.

$$\Pi(q_i,q_j,x_i,x_j) = \sum_{i=1}^{2}\{p_i q_i-(A-x_i-(1+\beta)x_j)q_i-\gamma\frac{x_i^2}{2}\}, \quad i\neq j, \tag{12}$$

over their control variable. Symmetric optimal quantities, when quantity is also the control variable, conditional on x $(=x_i=x_j)$ are

$$q_i(x) = \frac{(a-A)+(1+\beta)x}{2b(1+\theta)}, \quad i=1,2. \tag{13}$$

if firms set price in the second stage, then the symmetric equilibrium price

$$p_i(x) = \frac{(a-A)-(1+\beta)x}{2}, \quad i=1,2. \tag{14}$$

Of course, in case of a monopoly the choice of decision variable in the second stage is not important since monopoly profits will always be the same. As a consequence, profit conditional on the R&D investment is the same, whether firms set price or quantity in the second stage, and is given by

$$\Pi(x) = \frac{1}{2b(1+\theta)}[(a-A)+(1+\beta)x]^2-\gamma x^2. \tag{15}$$

Monopoly R&D investment maximizes this expression, and equals[20]

$$x_{III}^{C} = x_{III}^{B} = \frac{(a-A)(1+\beta)}{2b\gamma(1+\theta)-(1+\beta)^2}. \tag{16}$$

Having solved all three games we can compare R&D investments under the three different regimes. This leads to the following ranking

$$\begin{aligned} &x_I^C > x_{III}^C > x_{II}^C, \quad \beta\in[0,\frac{\theta(4+2\theta+\theta^2)}{8+8\theta+2\theta^2-\theta^3}),\\ &x_{III}^C > x_I^C > x_{II}^C, \quad \beta\in(\frac{\theta(4+2\theta+\theta^2)}{8+8\theta+2\theta^2-\theta^3},\frac{\theta}{2}),\\ &x_{III}^C > x_{II}^C > x_I^C, \quad \beta\in(\frac{\theta}{2},1], \end{aligned} \tag{17}$$

[20] With second order condition $2b\gamma(1+\theta)>(1+\beta)^2$.

in case of Cournot competition. Similar results hold under Bertrand competition

$$x_I^B > x_{III}^B > x_{II}^B, \quad \beta \in [0, \frac{\theta(4-2\theta-\theta^2)}{8-2\theta^2+\theta^3}),$$

$$x_{III}^B > x_I^B > x_{II}^B, \quad \beta \in (\frac{\theta(4-2\theta-\theta^2)}{8-2\theta^2+\theta^3}, \frac{\theta}{2-\theta^2}), \tag{18}$$

$$x_{III}^B > x_{II}^B > x_I^B, \quad \beta \in (\frac{\theta}{2-\theta^2}, 1].$$

Under both Cournot and Bertrand competition, cooperation in R&D and in either setting price or quantity leads in most cases to the highest level of R&D investment. DJ remark that "this stems from the fact that less competition in the product market allows the firms to capture more of the surplus created by their research and induce more R&D expenditures" (p. 1135). Deciding whether or not firms should be allowed to fully cooperate should however be based on the implications this agreement has on social welfare. It is to the analysis of these implications that we now turn.

4. A CASE FOR COOPERATION IN R&D?

As can be concluded from Section 3, the effect on private R&D investment (and hence on all other variables) of allowing firms to cooperate in R&D (i.e. to form R&D-cartels), to fully exchange innovative information (i.e. to form RJVs), or to do both (i.e. to form RJV-cartels) depends on the degree of product differentiation, on the extent to which technological knowledge leaks out and on the type of competition firms face in the second stage of the production process. In this section firms' (dis)incentives to cooperate in R&D and/or to fully exchange innovative information are contrasted with the effect these agreements have on social welfare. In order to do so we first have to solve the Cournot and Bertrand games, the results of which are summarized in Tables 1 and 2.

Table 1 Equilibrium Outcomes of the Non-Subsidized Cournot Games

No Cooperation in R&D, No Cooperation in Production

$$x_I^C = \frac{2(a-A)(2-\theta\beta)}{b\gamma(2+\theta)(4-\theta^2)-2(2-\theta\beta)(1+\beta)}$$

$$p_I^C = a-\frac{b\gamma(a-A)(4-\theta^2)(1+\theta)}{b\gamma(2+\theta)(4-\theta^2)-2(2-\theta\beta)(1+\beta)}$$

$$Q_I^C = \frac{2\gamma(a-A)(4-\theta^2)}{b\gamma(2+\theta)(4-\theta^2)-2(2-\theta\beta)(1+\beta)}$$

$$\pi_I^C = \frac{\gamma(a-A)^2[b\gamma(4-\theta^2)^2-2(2-\theta\beta)^2]}{[b\gamma(4-\theta^2)(2+\theta)-2(2-\theta\beta)(1+\beta)]^2} \qquad W_I^C = \frac{\gamma(a-A)^2[b\gamma(4-\theta^2)^2(3+\theta)-4(2-\theta\beta)^2]}{[b\gamma(2+\theta)(4-\theta^2)-2(2-\theta\beta)(1+\beta)]^2}$$

Cooperation in R&D, No Cooperation in Production

$$x_{II}^C = \frac{2(a-A)(1+\beta)}{b\gamma(2+\theta)^2-2(1+\beta)^2} \qquad P_{II}^C = a-\frac{b\gamma(a-A)(2+\theta)(1+\theta)}{b\gamma(2+\theta)^2-2(1+\beta)^2} \qquad Q_{II}^C = \frac{2\gamma(a-A)(2+\theta)}{b\gamma(2+\theta)^2-2(1+\beta)^2}$$

$$\pi_{II}^C = \frac{\gamma(a-A)^2}{b\gamma(2+\theta)^2-2(1+\beta)^2} \qquad W_{II}^C = \frac{\gamma(a-A)^2[b\gamma(3+\theta)(2+\theta)^2-4(1+\beta)^2]}{[b\gamma(2+\theta)^2-2(1+\beta)^2]^2}$$

Cooperation in R&D, Cooperation in Production

$$x_{III}^C = \frac{(a-A)(1+\beta)}{2b\gamma(1+\theta)-(1+\beta)^2} \qquad p_{III}^C = \frac{(a-A)[b\gamma(1+\theta)-(1+\beta)^2]}{2b\gamma(1+\theta)-(1+\beta)^2} \qquad Q_{III}^C = \frac{2\gamma(a-A)}{2b\gamma(1+\theta)-(1+\beta)^2}$$

$$\pi_{III}^C = \frac{\gamma(a-A)^2}{2[2b\gamma(1+\theta)-(1+\beta)^2]} \qquad W_{III}^C = \frac{\gamma(a-A)^2[3b\gamma(1+\theta)-(1+\beta)^2]}{[2b\gamma(1+\theta)-(1+\beta)^2]^2}$$

Table 2 Equilibrium Outcomes of the Non-Subsidized Bertrand Games[a]

	No Cooperation in R&D No Cooperation in Production	Cooperation in R&D No Cooperation in Production
x^B	$\frac{2(a-A)(2-\theta\beta-\theta^2)}{b\gamma(1+\theta)(2-\theta)(4-\theta^2)-2(1+\beta)(2-\theta\beta-\theta^2)}$	$\frac{2(a-A)(1-\theta)(1+\beta)}{b\gamma(1+\theta)(2-\theta)^2-2(1+\beta)^2(1-\theta)}$
p^B	$a-\frac{b\gamma(a-A)(4-\theta^2)(1+\theta)}{b\gamma(1+\theta)(2-\theta)(4-\theta^2)-2(1+\beta)(2-\theta\beta-\theta^2)}$	$a-\frac{b\gamma(a-A)(1+\theta)(2-\theta)}{b\gamma(1+\theta)(2-\theta)^2-2(1+\beta)^2(1-\theta)}$
Q^B	$\frac{2\gamma(a-A)(4-\theta^2)}{b\gamma(1+\theta)(2-\theta)(4-\theta^2)-2(1+\beta)(2-\theta\beta-\theta^2)}$	$\frac{2\gamma(a-A)(2-\theta)}{b\gamma(1+\theta)(2-\theta)^2-2(1+\beta)^2(1-\theta)}$
π^B	$\frac{\gamma(a-A)^2[b\gamma(1-\theta^2)(4-\theta^2)^2-2(2-\theta\beta-\theta^2)^2]}{[b\gamma(1+\theta)(2-\theta)(4-\theta^2)-2(1+\beta)(2-\theta\beta-\theta^2)]^2}$	$\frac{\gamma(a-A)^2(1-\theta)}{b\gamma(1+\theta)(2-\theta)^2-2(1+\beta)^2(1-\theta)}$
W^B	$\gamma(a-A)^2 \times \frac{[b\gamma(4-\theta^2)^2(3-2\theta)(1+\theta)-4(2-\theta\beta-\theta^2)^2]}{[b\gamma(1+\theta)(2-\theta)(4-\theta^2)-2(1+\beta)(2-\theta\beta-\theta^2)]^2}$	$\gamma(a-A)^2 \times \frac{[b\gamma(2-\theta)^2(1+\theta)(3-2\theta)-4(1-\theta)^2(1+\beta)^2]}{[b\gamma(1+\theta)(2-\theta)^2-2(1+\beta)^2(1-\theta)]^2}$

[a] See for the full cooperative regime Table 1.

We begin with examining RJVs. Simulation results indicate the following[21]

$$\frac{\partial W_I^C}{\partial \beta} > 0, \quad \forall \theta \in [0, 0.80],$$
$$\frac{\partial W_I^B}{\partial \beta} > 0, \quad \forall \theta \in [0, 0.44]. \tag{19}$$

These partial derivatives show that if products are differentiated at least to a modest degree ($\theta \leq 0.80$ in case of Cournot competition and $\theta \leq 0.44$ for Bertrand behaviour) RJVs are socially desirable. On the other hand, and especially in case of Bertrand competition, when products are homogeneous it could be socially harmful to allow firms to fully exchange innovative information. Further observe that $\partial \pi_I^C / \partial \beta > 0$ for $\theta \in [0,1]$ and $\partial \pi_I^B / \partial \beta > 0$ for $\theta \in [0, 0.47]$, i.e. firms are always willing to exchange innovative information voluntarily if they are engaged in Cournot competition, or if they face Bertrand competition and products are differentiated at least to a modest degree. Note however that in case of both Cournot and Bertrand competition firms are willing to fully share information when it is socially beneficial to allow them to do so (see (19)).

Second, we investigate R&D-cartels. From a social welfare point of view we have as ranking for Cournot competition[22]

---

[21] Whenever possible analytical expressions are derived. However, sometimes these are too complicated to be interpreted. In these cases we rely on numerical approximations. The numbers given in the text always refer to the case in which the various second order and stability conditions are just met in order to highlight the role of θ and β. In effect this means that we set $b\gamma$ equal to 3 in case of second stage Cournot competition while under Bertrand behaviour $b\gamma$ equals $2(2-\theta\beta-\theta^2)^2/(1-\theta^2)(4-\theta^2)^2$. Indeed, if $b\gamma$ is arbitrarily large, the influence of either θ or β becomes negligible. However, all numerical approximations stated in the paper are valid for (at least) $b\gamma \in [3, 1 \cdot 10^{11}]$ under Cournot and for $b\gamma \in [\kappa, \infty)$ under Bertrand, where κ is the above mentioned value. Clearly this includes all interesting parameter configurations, i.e. the numerical values presented are generally valid. Finally observe that nowhere is the size of $(a-A)$ of importance.

[22] For $\beta = \theta/2$ we have as ranking $W_I^C = W_{II}^C > W_{III}^C$, and for $\beta = \delta$ this reads $W_{II}^C > W_I^C = W_{III}^C$.

$$W_I^C > W_{II}^C > W_{III}^C \quad \forall \beta \in [0, \frac{\theta}{2}),$$

$$W_{II}^C > W_I^C > W_{III}^C \quad \forall \beta \in (\frac{\theta}{2}, \delta), \tag{20}$$

$$W_{II}^C > W_{III}^C > W_I^C \quad \forall \beta \in (\delta, 1].$$

where simulations indicate that $\delta \approx \theta$. Similar results hold for the Bertrand case[23]

$$W_I^B > W_{II}^B > W_{III}^B \quad \forall \beta \in [0, \frac{\theta}{(2-\theta^2)}),$$

$$W_{II}^B > W_I^B > W_{III}^B \quad \forall \beta \in (\frac{\theta}{(2-\theta^2)}, 1]. \tag{21}$$

These comparisons show that independent of the size of technological spillovers, of the extent to which products are differentiated and of the type of competition firms face in the second stage, social welfare of the second game always exceeds that of the third, i.e. *it is always socially harmful if firms extend their R&D-collusive agreement to the production stage*. Further, allowing firms to form R&D-cartels is only socially beneficial if technological spillovers are of considerable size relative to the extent that products are differentiated (i.e. $\beta > \theta/2$ for Cournot competition and $\beta > \theta/(2-\theta^2)$ for Bertrand competition). Finally, under second stage Betrand competition social welfare of the full competitive game always exceeds that of the monopoly, while under Cournot behaviour this depends on whether or not technological spillovers exceed the degree of product differentiation.

[23] This ranking is $W_I^B = W_{II}^B > W_{III}^B$ for $\beta = \theta/(2-\theta^2)$.

Comparing now the profits of a single firm for the respective games reveals that[24]

$$\pi_I^C < \pi_{II}^C < \pi_{III}^C \quad \forall\beta\in[0,\frac{\theta}{2})\cup(\frac{\theta}{2},1],$$
$$\pi_I^B < \pi_{II}^B < \pi_{III}^B \quad \forall\beta\in[0,\frac{\theta}{2-\theta^2})\cup(\frac{\theta}{2-\theta^2},1], \tag{22}$$

which indicates that *irrespective of the degree of product differentiation, the size of technological spillovers and the type of competition firms always want to collude in as many stages as allowed to.* The threat that firms will extend the R&D-collusive agreement to the production stage is apparent.

Finally, we analyze RJV-cartels. If firms are allowed to cooperate in R&D it is always socially beneficial to allow them to fully exchange their innovative information.[25] That is, both in case of Cournot and Bertrand competition existing R&D-cartels should be allowed to extend their agreement to a RJV-cartel. And firms are willing to do so since $\partial\pi_{II}^C/\partial\beta$ and $\partial\pi_{II}^B/\partial\beta$ are positive $\forall\theta\in[0,1]$. Moreover, according to (20) and (21) allowing for RJV-cartels is also social welfare enhancing compared to the fully competitive regime (either in case of R&D-competition or RJVs).

To conclude, based on a comparison of social welfare, firms should only be allowed to cooperate in R&D when spillovers are substantial relative to the degree of product differentiation (that is, $\beta>\theta/2$ in case of Cournot competition and $\beta>\theta/(2-\theta^2)$ when firms compete in prices), and this collusive agreement should be that of a RJV-cartel (in which case spillovers are maximal). Implementation of this policy will not be frustrated by producers since it is also in their interest to collude in R&D and to fully exchange innovative information. However, this policy will evoke the danger of increased monopoly power since firms are tempted to extend the collusive agreement to the production stage. Compared to the fully non-cooperative game this will lead to a social welfare loss, both in case of Cournot and Bertrand competition if products are not differentiated to a high degree (i.e. $\theta>0.2$). Let us consider therefore another R&D-stimulating policy: that of subsidizing private R&D.

---

[24] When $\beta=\theta/2$ we have for the Cournot case $\pi_I = \pi_{II} < \pi_{III}$, while for $\beta=\theta/(2-\theta^2)$ this ranking reads in case of Bertrand competition $\pi_I = \pi_{II} < \pi_{III}$.

[25] Observe that $\partial W_{II}^C/\partial\beta$ and $\partial W_{II}^B/\partial\beta$ are positive $\forall\theta\in[0,1]$.

5. R&D-SUBSIDIES: COURNOT AND BERTRAND

Following Spencer and Brander (1983) we introduce a R&D-subsidy, *s*, per unit of R&D. It is assumed that, in order to finance the total R&D-subsidy, firms are taxed for it in the output stage. In other words, we consider a balanced-budget policy.[26] By providing a R&D-subsidy, the government changes the cost structure of the R&D stage, and thus changes the set of actions (output or prices and R&D expenditures) which are compatible with the two-stage Nash-Cournot equilibrium.[27] However, the taxation in the output stage does not affect the product market equilibrium in that the appropriate lump-sum tax is deducted from firms' profits after the Nash-Cournot equilibrium is computed. Differences in equilibrium profits and welfare with respect to Section 3 reflect only the influence of the subsidy.

Given the demand, production and cost structures outlined in Section 2, profits of a single firms with R&D-subsidies (and before imposing the lump-sum tax) are given by

$$\pi_i(q_i,q_j,p_i,p_j,x_i,x_j,s) = p_i q_i - (A - x_i - x_j) q_i - \gamma \frac{x_i^2}{2} + s x_i, \tag{23}$$

for $i,j=1,2,\ i \neq j$. Of course, social welfare is still given by (5). Observe that the R&D-subsidies directly affect the R&D investment, but not *the way* in which R&D investment is related to output or price. That is, the analyses of second stage behaviour remain unchanged with respect to those presented in Section 3. In what follows we will therefore only explicitly consider the R&D setting stage and the derivations of optimal R&D subsidies.

5.1 SUBSIDIZING COMPETITIVE R&D

Cournot and Bertrand profits, conditional on the optimal R&D subsidies, are given by (see also (8))

---

[26] One of the disadvantages of subsidizing R&D is the distortionary effect of taxes which are needed to raise the necessary revenue. We abstract partially from this effect by assuming that firms pay a Pigou-tax.

[27] Note that firms cannot establish this alteration in cost structure themselves, since, by definition of a Nash-Cournot equilibrium, it is not in their interest to shift financial resources from the output stage to the R&D stage.

$$\pi_i^C(x_i,x_j;s) = \frac{1}{b(4-\theta^2)^2}[(a-A)(2-\theta)+(2-\theta\beta)x_i+(2\beta-\theta)x_j]^2 \\ -\gamma\frac{x_i^2}{2}+sx_i \tag{24a}$$

and

$$\pi_i^B(x_i,x_j;s) = \frac{(1-\theta)}{b(1+\theta)(2-\theta)} \\ \times[(a-A)-\frac{(2-\theta\beta-\theta^2)x_i+(2\beta-\theta-\theta^2\beta)x_j}{(1-\theta)(2+\theta)}]^2 \\ -\gamma\frac{x_i^2}{2}+sx_i, \tag{24b}$$

respectively, for $i,j=1,2,\ i\neq j$. The associated R&D-reaction functions are[28]

$$x_i^C(x_j^C) = \frac{2(a-A)(2-\theta)(2-\theta\beta)+(4-\theta^2)^2bs}{b\gamma(4-\theta^2)^2-2(2-\theta\beta)^2} \\ +\frac{2(2-\theta\beta)(2\beta-\theta)}{b\gamma(4-\theta^2)^2-2(2-\theta\beta)^2}x_j^C, \tag{25a}$$

$$x_i^B(x_j^B) = \frac{2(a-A)(1-\theta)(2+\theta)(2-\theta\beta-\theta^2)+(1-\theta^2)(4-\theta^2)^2bs}{b\gamma(1-\theta^2)(4-\theta^2)^2-2(2-\theta\beta-\theta^2)^2} \\ +\frac{2(2-\theta\beta-\theta^2)(2\beta-\theta-\theta^2\beta)}{b\gamma(1-\theta^2)(4-\theta^2)^2-2(2-\theta\beta-\theta^2)^2}x_j^B. \tag{25b}$$

Stability conditions are still given by (9). From (25) equilibrium R&D investments are now readily derived

[28] Second order conditions are those stated in Section 3.1.

$$x_I^{\,C}(s) = \frac{2(a-A)(2-\theta\beta)+(2+\theta)(4-\theta^2)bs}{b\gamma(2+\theta)(4-\theta^2)-2(2-\theta\beta)(1+\beta)}, \tag{26a}$$

$$x_I^{\,B}(s) = \frac{2(a-A)(2-\theta\beta-\theta^2)+(2-\theta)(1+\theta)(4-\theta^2)bs}{b\gamma(1+\theta)(2-\theta)(4-\theta^2)-2(2-\theta\beta-\theta^2)(1+\beta)}. \tag{26b}$$

Observe that social welfare equals

$$W^C(s) = \frac{(3+\theta)}{b(2+\theta)^2}[(a-A)+(1+\beta)x^C(s)]^2-\gamma x^C(s)^2, \tag{27a}$$

$$W^B(s) = \frac{(3-2\theta)}{b(2-\theta)^2(1+\theta)}[(a-A)+(1+\beta)x^B(s)]^2-\gamma x^B(s)^2. \tag{27b}$$

Maximizing (27) with respect to s results in the optimal R&D subsidies for the fully competitive games[29]

$$s_I^{\,C} = \frac{\gamma(a-A)[(3+\theta)(2-\theta)(1+\beta)-2(2-\theta\beta)]}{(2-\theta)[b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2]}, \tag{28a}$$

$$s_I^{\,B} = \frac{\gamma(a-A)[(2+\theta)(3-2\theta)(1+\beta)-2(2-\theta\beta-\theta^2)]}{(2+\theta)[b\gamma(2-\theta)^2(1+\theta)-(3-2\theta)(1+\beta)^2]}. \tag{28b}$$

When R&D-subsidies are provided technological spillovers affect R&D-investments in two opposite ways; one direct and one indirect. On the one hand R&D investments will fall if spillovers increase, due to diminishing appropriability and possible strengthening of competitors. On the other hand, from (28) it is readily derived that R&D-subsidies are increasing in spillovers.[30] That is, the incentive reducing effect of increasing technological spillovers on R&D-investment is parried by an increasing subsidy. The net effect of these two forces is positive[31] implying that optimal R&D-subsidies more than offset the dis-incentives to invest in R&D due to increasing technological spillovers. If

[29] Under Cournot competition the second order condition is that $b\gamma(2+\theta)^2>(3+\theta)(1+\beta)^2$, while under Bertrand competition we impose that $b\gamma(2-\theta)^2(1+\theta)>(1+\beta)^2(3-2\theta)$.

[30] See footnote 19.

[31] See the proof of Proposition 2 below.

technological spillovers are completely internalized by allowing firms to form a RJV, wasteful duplication is eliminated and research is at maximum effectiveness (with respect to technological spillovers). In that case, therefore, R&D-subsidies are at their maximum.

5.2 SUBSIDIZING R&D-CARTELS.

Second stage joint profits are now given by

$$\Pi^C(x_i,x_j) = \frac{1}{b(4-\theta^2)^2} \times \sum_{i=1}^{2} \{[(a-A)(2-\theta)+(2-\theta\beta)x_i+(2\beta-\theta)x_j]^2 - \gamma\frac{x_i^2}{2}+sx_i\}, \tag{29a}$$

$$\Pi^B(x_i,x_j) = \frac{(1-\theta)}{b(1+\theta)(2-\theta)} \times \sum_{i=1}^{2} \{[(a-A)+\frac{(2-\theta\beta-\theta^2)x_i+(2\beta-\theta-\theta^2\beta)x_j}{(1-\theta)(2+\theta)}]^2 - \gamma\frac{x_i^2}{2}+sx_i\}. \tag{29b}$$

Symmetric equilibrium levels of R&D, which follow from maximizing (29) over x_i, $i=1,2$, $i\neq j$, conditional on the R&D-subsidy, are given by[32]

$$x_{II}^C(s) = \frac{2(a-A)(1+\beta)+(2+\theta)^2 bs}{b\gamma(2+\theta)^2-2(1+\beta)^2}, \tag{30a}$$

$$x_{II}^B(s) = \frac{2(a-A)(1-\theta)(1+\beta)+(1+\theta)(2-\theta)^2 bs}{b\gamma(1+\theta)(2-\theta)^2-2(1-\theta)(1+\beta)^2}. \tag{30b}$$

[32] Second order conditions are those stated in Section 3.2.

Social welfare as a function of R&D, conditional on the R&D-subsidy, is still given by (27), where the respective R&D investments are given by (30). Maximizing these expressions for social welfare with respect to s leads to[33]

$$s_{II}^{C} = \frac{\gamma(a-A)(1+\beta)(1+\theta)}{b\gamma(2+\theta)^2-(1+\beta)^2(3+\theta)}, \tag{31a}$$

$$s_{II}^{B} = \frac{\gamma(a-A)(1+\beta)}{b\gamma(1+\theta)(2-\theta)^2-(1+\beta)^2(3-2\theta)}. \tag{31b}$$

Also when firms are allowed to cooperate in R&D the optimal R&D-subsidies are increasing in the spillover-rate, and are at their maximum when information is fully shared. Since subsidized cooperative R&D is also increasing in the rate of technological spillovers[34], exchanging innovative information has in this case a double stimulating effect on R&D investments: directly because of increased synergy (recall Section 3.2), and indirectly through the R&D-subsidy. Further, comparing the R&D-subsidies of the fully non-cooperative regime with those of the partial collusive game reveals that under Cournot competition the latter exceeds the former if $\beta>\theta/2$, while under Bertrand this holds for $\beta>\theta/(2-\theta^2)$. Recalling from Section 3.2 that non-cooperative R&D exceeds cooperative R&D whenever the spillover-rate is below $\theta/2$ for Cournot competition, and below $\theta/(2-\theta^2)$ for Bertrand competition, (whereas the opposite holds for larger spillovers) we see that the optimal R&D-subsidies bring the levels of cooperative and non-cooperative R&D together. In fact, they will ensure that both investments are *exactly the same*, whether firms compete in price or quantity. The implications of this convergence will be explored in more detail in Section 6.

[33] Second order conditions under Cournot and Bertrand competition are respectively $(3+\theta)(1+\beta)^2<b\gamma(2+\theta)^2$ and $(3-2\theta)(1+\beta)^2<b\gamma(2-\theta)^2(1+\theta)$.

[34] See footnote 19.

5.3 SUBSIDIZING MONOPOLIES

Monopoly profits with R&D-subsidies equal

$$\Pi(q_i,q_j,x_i,x_j) = \sum_{i=1}^{2}\{p_i q_i - (A - x_i - (1+\beta)x_j)q_i - \gamma\frac{x_i^2}{2} + s x_i\}, \quad i \neq j. \tag{32}$$

Maximizing (32) with respect to quantities yields (13) while (14) is the equilibrium price under Bertrand competition (in both cases, R&D investments are of course a function of *s*). Both under Cournot and Bertrand competition, first stage monopoly profits equal

$$\Pi(x) = \frac{1}{2b(1+\theta)}[(a-A)+(1+\beta)x]^2 - \gamma x^2 + s x. \tag{33}$$

R&D-investments which maximize (33) conditional on *s* equal[35]

$$x_{III}^C(s) = x_{III}^B(s) = \frac{(a-A)(1+\beta)+2(1+\theta)bs}{2b\gamma(1+\theta)-(1+\beta)^2}. \tag{34}$$

Social welfare in case of a monopoly is given by

$$W_{III} = \frac{3}{4b(1+\theta)}[(a-A)+(1+\beta)x(s)]^2 - \gamma x(s)^2. \tag{35}$$

with $x(s)$ given by (34). The optimal R&D-subsidy which maximizes (35) turns out to be[36]

$$s_{III}^C = s_{III}^B = \frac{\gamma(a-A)(1+\beta)}{4b\gamma(1+\theta)-3(1+\beta)^2}. \tag{36}$$

Even when firms are completely integrated there is an incentive for a government to subsidize R&D for which the monopolist is taxed when producing with the new process. Although a monopolist is more able to appreciate the returns of its R&D-investment due to increased market power, there is still room for additional stimulation of research.

---

[35] The second order is that stated in Section 3.3.

[36] With second order condition $4b\gamma(1+\theta)>3(1+\beta)^2$.

6. DISCUSSION

Should a government provide R&D-subsidies, should it allow individual firms to cooperate in R&D, should it encourage firms to fully exchange information, or should it implement a combination of these options? With the analysis of the previous section we are able to shed some light on these issues. In what follows we first examine whether or not providing R&D-subsidies for which firms are taxed in the output stage is a socially desirable policy. Proposition 1 shows that it is. We then proceed by analyzing the first main theme of the paper; comparing the R&D-stimulating effect of providing direct R&D-subsidies with that of allowing firms to cooperate in R&D. It appears that in general the former policy is more effective than the latter in promoting private R&D. This statement is formalized in the second Proposition. We then analyze what combination of R&D-stimulating instruments will lead to the highest level of private R&D. Finally we arrive at the second main issue of the paper; according to social welfare, what is the optimal 'policy mix'? For a number of reasons, which will be explained below, we conclude that a government should subsidize RJVs. That is, firms should *not* be allowed to form R&D-cartels or RJV-cartels.[37]

Consideration of the sign and effects of optimal R&D subsidies for which firms are taxed in the output stage leads to the following proposition, the proof of which is given in Appendix 1.

PROPOSITION 1

For all three games considered, both under second stage Cournot and Bertrand competition, and irrespective of the size of technological spillovers and the extent to which products are differentiated, (i) the optimal R&D-subsidy is positive and (ii) subsidizing R&D optimally increases the level of R&D, output and social welfare, but lowers prices and net profits.

---

[37] It should be noted, however, that the model employed here is highly stylized. The policy recommendations stated in this section should therefore be considered as tentative. Research based on more general models should give more definitive answers as to whether governments should subsidize R&D and/or allow for R&D-collusion.

Providing optimal R&D-subsidies for which firms are taxed in the output stage increases consumers' surplus but lowers producers' surplus. According to Proposition 1 the former effect dominates the latter with the net result that social welfare increases.[38] Obviously consumers' surplus is well served by lower prices and higher output. Profits on the other hand are affected in three ways; total revenue ($p_i q_i$) and marginal cost ($A - x_i - \beta x_j$) drop while expenditures on R&D ($\gamma x_i^2/2$) increase.[39] The efficiency gain is not enough to cover the loss in total revenue and the additional cost of R&D-investment, with the net result that profits fall.[40] It could be argued therefore that firms are not interested in R&D-subsidies since it lowers their net profits. But if a government wants to increase social welfare it can always tax firms and set R&D-subsidies accordingly. Given the nature of a Nash equilibrium, firms' best responses are then given by the equilibria as computed in the previous section.

On the other hand, R&D-subsidies must be provided with care, because excessive R&D investments (due to excessive R&D-subsidies) could be socially undesirable.[41] In practise this means that adequate estimates are required of the parameters determining the optimal R&D-subsidy. In the model employed here the social welfare function is quadratic in s. Therefore, R&D-subsidies

---

[38] Spencer and Brander (1983) report similar results. Their findings are more robust in that they consider a more general model than the one employed here. Also, we assume that both firms receive the same subsidy while Spencer and Brander (1983) examine the case in which either only one firms' R&D is subsidized or both firms independently receive a R&D-subsidy (each from their own government). On the other hand we explicitly treat consumers' surplus as a component of social welfare, allow products to be differentiated and explicitly consider technological spillovers whereas Spencer and Brander (1983) only investigate changes in producers' surplus due to government intervention in markets for homogeneous products where technological spillovers are absent.

[39] The fact that total revenue drops is not immediate from Proposition 1 since prices fall but production increase. That nevertheless their products drop is straightforward to calculate from Tables 1 to 4 and therefore left as an exercise for the reader.

[40] This observation however neglects the revenues in time of successful R&D. Because we consider only a static model, in each period firms have to invest in R&D. But if firms can use the innovated process for several periods, they can invest less in R&D in periods after the first. In these subsequent periods the efficiency gain accomplished in the first period may well outweigh the loss in total revenue and the increased first period R&D-investment. These issues should however be considered more thoroughly in a dynamic setting, a task we will not pursue in this paper.

[41] See Reinganum (1989).

exceeding two times their optimal value are socially harmful. This means that, for instance, over estimating the spillover effect can lead to excessive R&D promotion, since all optimal subsidies are increasing in β.

Having established the desirability of providing R&D-subsidies we can now compare its effect on R&D-investment with that of allowing firms to form RJVs, R&D-cartels or RJV-cartels. The next proposition summarizes this comparison.

PROPOSITION 2

To promote private R&D, both under second stage Cournot and Bertrand competition, subsidizing non-collusive R&D optimally is more effective than (i) permitting R&D-cartels or (ii) allowing firms to engage in RJVs without subsidization.

PROOF

part (i)

Comparing the equilibrium levels of non-cooperative, subsidized R&D ($x_{I_s}^C$ and $x_{I_s}^B$ under Cournot and Bertrand competition respectively), with the non-subsidized R&D investment in the R&D-cartel (x_{II}^C and x_{II}^B) reveals that

$$x_{I_s}^C = x_{II}^C\{1 + \frac{b\gamma(2+\theta)^2(1+\theta)}{2[b\gamma(2+\theta)^2 - (3+\theta)(1+\beta)^2]}\},$$

$$x_{I_s}^B = x_{II}^B\{1 + \frac{b\gamma(1+\theta)(2-\theta)^2}{2(1-\theta)[b\gamma(1+\theta)(2-\theta)^2 - (1+\beta)^2(3-2\theta)]}\}.$$

Appropriate second order conditions ensure that the expressions in brackets exceed 1.

Part (ii)

The partial derivatives of non-collusive subsidized R&D with respect to β equal

$$\frac{\partial x_{Is}^{C}}{\partial \beta} = \frac{(a-A)(3+\theta)[b\gamma(2+\theta)^2+(3+\theta)(1+\beta)^2]}{[b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2]^2} > 0,$$

$$\frac{\partial x_{Is}^{B}}{\partial \beta} = \frac{(a-A)(3-2\theta)[b\gamma(1+\theta)(2-\theta)^2+(1+\beta)^2(3-2\theta)]}{[b\gamma(1+\theta)(2-\theta)^2-(1+\beta)^2(3-2\theta)]^2} > 0.$$

Then, realizing that

$$x_{Is}^{C}\big|_{\beta=0} - x_{I}^{C}\big|_{\beta=1} = \frac{(a-A)[b\gamma(1+\theta)(2+\theta)^2-2(3+\theta)]}{[b\gamma(2+\theta)^2-(3+\theta)][b\gamma(2+\theta)^2-4]} > 0,$$

$$x_{Is}^{B}\big|_{\beta=0} - x_{I}^{B}\big|_{\beta=1} = \frac{(a-A)}{b\gamma(1+\theta)(2-\theta)^2-(3-2\theta)}$$

$$\times \frac{b\gamma(1+\theta)(2-\theta)^2-2(1-\theta)(3-2\theta)}{b\gamma(1+\theta)(2-\theta)^2-4(1-\theta)} > 0.$$

completes the proof, since $x_I^C\big|_{\beta=1}$ and $x_I^B\big|_{\beta=1}$ are the non-subsidized equilibrium investments in a RJV under second stage Cournot and Bertrand competition respectively.

■

In the model used here, forming a RJV does not increase R&D investment because of diminishing appropriability of research efforts when spillovers increase.[42] Moreover, since the R&D-stimulating effect of an optimal R&D-subsidy is stronger than the non-appropriability incentive (see Section 5.1), it is readily derived that subsidizing non-collusive R&D is more effective than allowing firms to form RJVs.

More important, however, is that providing R&D-subsidies is more effective than allowing firms to form a R&D-cartel.[43] Possible synergetic

[42] Observe that $\partial x_I^C/\partial\beta, \partial x_I^B/\partial\beta < 0$.

[43] In general this is not true for a RJV-cartel. Comparing subsidized non-cooperative R&D with R&D investments of a RJV-cartel under second stage Cournot competition reveals that the former exceeds the latter whenever $b\gamma(2+\theta)^2[\beta(3+\theta)-(1-\theta)]>4(1-\beta^2)(3+\theta)$. Letting $b\gamma\geq 3$ implies that the inequality holds $\forall\theta\in[0,1)$ if $\beta\geq 0.56$. Under second stage

effects coming from R&D-collusive agreements can be mimicked (more) effectively through R&D-subsidies. This observation is important when deciding what R&D-stimulating policy to implement. In particular it is doubtful whether stimulating private R&D at the cost of giving firms additional market power is the appropriate policy to follow, knowing that a more effective instrument is at hand which also preserves the control over market power with the authorities.

We proceed with examining what combination of R&D-enhancing instruments will lead to the highest level of private R&D. In order to address this issue, all subsidy-games have to be solved completely, the results of which are summarized in Tables 3 and 4. An immediate result of this exercise is stated in the next proposition.

PROPOSITION 3

Both under second stage Cournot and Bertrand competition subsidizing non-cooperative R&D or subsidizing a R&D-cartel leads to the same market outcome and social welfare.

Proposition 3 states that encouraging R&D investments by allowing firms to participate in R&D-cartels *and in addition* subsidizing this agreement accordingly, has the same effect on market performances and social welfare as subsidizing non-cooperative R&D. Since Proposition 3 holds for all values of β, it is in particular valid for $\beta = 1$, i.e. both under second stage Cournot and Bertrand competition optimally subsidising a RJV leads to the same market outcome and social welfare as optimally subsidizing a RJV-cartel. According to Proposition 3, in terms of market outcomes and social welfare, there is no need for relaxing antitrust laws which in effect indicates that R&D-cooperation is redundant.

In Section 3 we concluded that in most cases the full cooperative regime leads to the highest level of R&D. With R&D-subsidies available the opposite holds. *Both under Cournot and Bertrand competition a subsidized monopoly will always invest less in R&D compared to either the competitive or partial collusive regimes.*[44] The ability to appropriate more the returns to R&D when

---

Bertrand competition subsidized competitive R&D-investment exceeds that of a RJV-cartel if $b\gamma(1+\theta)(2-\theta)^2[\beta(3-2\theta)-(1-2\theta)]>4(1-\beta^2)(3-2\theta)(1-\theta)$. Given the second order condition $b\gamma \geq 2(2-\theta\beta-\theta^2)^2/(1-\theta^2)(4-\theta^2)^2$ this holds $\forall \theta \in [0,1)$ if $\beta \geq 0.86$.

[44] See Appendix 2.

Table 3 Equilibrium Outcomes of the Subsidized Cournot Games

	No Cooperation in R&D No Cooperation in Production	Cooperation in R&D No Cooperation in Production	Cooperation in R&D Cooperation in Production
s^C	$\frac{\gamma(a-A)}{(2-\theta)} \times \frac{(3+\theta)(2-\theta)(1+\beta)-2(2-\theta\beta)}{b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2}$	$\frac{\gamma(a-A)(1+\beta)(1+\theta)}{b\gamma(2+\theta)^2-(1+\beta)^2(3+\theta)}$	$\frac{\gamma(a-A)(1+\beta)}{4b\gamma(1+\theta)-3(1+\beta)^2}$
x_s^C	$\frac{(a-A)(1+\beta)(3+\theta)}{b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2}$		$\frac{3(a-A)(1+\beta)}{4b\gamma(1+\theta)-3(1+\beta)^2}$
p_s^C	$a-\frac{b\gamma(a-A)(2+\theta)(1+\theta)}{b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2}$		$\frac{(a-A)[2b\gamma(1+\theta)-3(1+\beta)^2]}{4b\gamma(1+\theta)-3(1+\beta)^2}$
Q_s^C	$\frac{2\gamma(a-A)(2+\theta)}{b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2}$		$\frac{4\gamma(a-A)}{4b\gamma(1+\theta)-3(1+\beta)^2}$
π_s^C	$\frac{\gamma(a-A)^2[2b\gamma(2+\theta)^2-(1+\beta)^2(3+\theta)^2]}{2[b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2]^2}$		$\frac{\gamma(a-A)^2[8b\gamma(1+\theta)-9(1+\beta)^2]}{2[4b\gamma(1+\theta)-3(1+\beta)^2]^2}$
W_s^C	$\frac{\gamma(a-A)^2(3+\theta)}{b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2}$		$\frac{3\gamma(a-A)^2}{4b\gamma(1+\theta)-3(1+\beta)^2}$

competition is diminished in the product market is more than offset by providing R&D subsidies. Projects in which firms are allowed to jointly explore the benefits of their collusive R&D in order to enhance R&D-investments (but at the cost of giving them more market power) are difficult to defend when the provision of R&D-subsidies is a viable alternative.

That R&D-subsidies strongly counter the inability of firms to appropriate the returns to their R&D-investments when confronted with competition in the product market can also be seen in another way. It is well known that Cournot markets are associated with less competition than Bertrand markets.[45] Indeed,

[45] See Singh and Vives (1984) and Vives (1985).

Table 4 Equilibrium Outcomes of the Subsidized Bertrand Games[a]

	No Cooperation in R&D No Cooperation in Production	Cooperation in R&D No Cooperation in Production
s^B	$\dfrac{\gamma(a-A)[(2+\theta)(3-2\theta)(1+\beta)-2\delta_1]}{(2+\theta)[b\gamma(2-\theta)^2(1+\theta)-(3-2\theta)(1+\beta)^2]}$	$\dfrac{\gamma(a-A)(1+\beta)}{b\gamma(1+\theta)(2-\theta)^2-(1+\beta)^2(3-2\theta)}$
x_s^B	$\dfrac{(a-A)(1+\beta)(3-2\theta)}{b\gamma(1+\theta)(2-\theta)^2-(1+\beta)^2(3-2\theta)}$	
p_s^B	$a-\dfrac{b\gamma(a-A)(1+\theta)(2-\theta)}{b\gamma(2-\theta)^2(1+\theta)-(3-2\theta)(1+\beta)^2}$	
Q_s^B	$\dfrac{2\gamma(a-A)(2-\theta)}{b\gamma(2-\theta)^2(1+\theta)-(3-2\theta)(1+\beta)^2}$	
π_s^B	$\dfrac{\gamma(a-A)^2[2b\gamma(1-\theta^2)(2-\theta)^2-(1+\beta)^2(3-2\theta)^2]}{2[b\gamma(2-\theta)^2(1+\theta)-(3-2\theta)(1+\beta)^2]^2}$	
W_s^B	$\dfrac{\gamma(a-A)^2(3-2\theta)}{b\gamma(2-\theta)^2(1+\theta)-(3-2\theta)(1+\beta)^2}$	

[a] See for the full cooperative regime Table 3.

the R&D-levels under Cournot competition exceed those under Bertrand competition in absence of a R&D-subsidy, both in case of competitive and cooperative R&D.[46] This of course is precisely due to the ability of firms to appreciate more the returns to research when confronted with Cournot competition than under Bertrand behaviour. With R&D-subsidies provided however, the reverse holds. Although firms face more competition under Bertrand than under Cournot, they invest more in R&D in case they set prices in the output stage when R&D is subsidized.[47] The reason for this reversal is

[46] See appendix 2.

[47] See appendix 2.

twofold. First, the R&D-subsidies under Bertrand exceed those under Cournot, and second, the effect on R&D-investment of the subsidy is less under Cournot than under Bertrand competition.[48]

We close this discussion with the second main theme of the paper: establishing the optimal R&D-stimulating policy. As in Section 4 we contrast private and social incentives. Beginning with the former observe that

$$\left.\begin{array}{l}\pi_{Is}^{C} = \pi_{IIs}^{C} < \pi_{IIIs}^{C},\\ \pi_{Is}^{B} = \pi_{IIs}^{B} < \pi_{IIIs}^{B}.\end{array}\right. \qquad \forall\theta \in [0,1),\ \beta \in [0,1],$$

Firms' objectives are clear; both under second stage Cournot and Bertrand competition they want to collude in as many stages as allowed to in order to make as much profits as possible. The following comparisons show that for both kinds of second stage competition this pursuit for additional market power is not without cost

$$\left.\begin{array}{l}W_{Is}^{C} = W_{IIs}^{C} < W_{IIIs}^{C},\\ W_{Is}^{B} = W_{IIs}^{B} < W_{IIIs}^{B}.\end{array}\right. \qquad \forall\theta \in [0,1),\ \beta \in [0,1],$$

Indeed, a subsidized monopoly is both under Cournot and Bertrand competition undesirable, which confirms the obvious consequence of Proposition 3; firms should not be allowed to form (subsidized) R&D-cartels or (subsidized) RJV-cartels. Instead, the authorities should provide optimal R&D-subsidies in markets where research is independently undertaken.

Finally it should be noted that both W_{Is}^{C} and W_{Is}^{B} are increasing in the spillover rate.[49] This means that the optimal policy for authorities to follow is to encourage firms to form RJVs (i.e. full exchange of technological information after independent R&D) and to subsidize this agreement accordingly. This policy not only leads to the highest level of private R&D investment[50] and social

[48] See footnote 19.

[49] $\partial W_{Is}^{C}/\partial\beta$ and $\partial W_{Is}^{B}/\partial\beta$ are positive $\forall\beta \in [0,1]$.

[50] Note that $\partial x_{Is}^{C}/\partial\beta$ and $\partial x_{Is}^{B}/\partial\beta$ are positive.

welfare, but also preserves the control over market power by the authorities.[51]

7. CONCLUSIONS

Comparing the effect on private R&D investments of allowing firms to collude in R&D with that of providing optimal R&D-subsidies (for which firms are taxed in the product market) reveals that both under Cournot and Bertrand competition in general the latter policy is more effective than the former in promoting R&D activity. Analyzing the implementation of both policies *simultaneously* reveals that if firms compete in either price or quantity (i) allowing firms to collude in R&D is redundant if the provision of R&D-subsidies is feasible and (ii) firms should only be encouraged to share their (independent) research outcomes (i.e. to form RJVs) and this agreement should be subsidized accordingly.[52]

Subsidizing RJVs has the obvious advantage of not having to abandon antitrust legislation concerning private R&D. Further, the dissemination of innovations is complete implying that duplication of research is absent. Moreover, lowering the (marginal) cost of R&D lowers entry barriers which in turn will trigger competition both in the R&D stage and the product market.

The analysis presented here is a first step in assessing the impact of *simultaneously* subsidizing private R&D activity and allowing firms to collude in R&D. It should be noted that the whole exercise is based on the synthesis of two stylized models in which many aspects of demand and supply structures in general and of the process of R&D in particular are neglected. The policy implications are therefore tentative and a more general analysis of the same issue should lead to more robust conclusions.

---

[51] To the extent that firms are able to share information concerning product market (pricing) behaviour when exchanging technological knowledge, some control over market power is given up by allowing firms to join RJVs. This threat, however, is much more apparent (and the actions of firms much more effective) when producers are allowed to coordinate their R&D-investment so as to maximize overall profits (i.e. to form R&D-cartels). See also Martin (1994b).

[52] One way of implementing this policy is to confront firms with a Pigou-tax and to give them a R&D-subsidy *if* they circulate the outcomes of their R&D activities.

REFERENCES

D'Aspremont, C. and Jacquemin, A., 1988, "Cooperative and Noncooperative R&D in Duopoly with Spillovers", *American Economic Review*, Vol.78, 1133-7.

D'Aspremont, C. and Jacquemin, A., 1990, "Cooperative and Noncooperative R&D in Duopoly with Spillovers: Erratum", *American Economic Review*, Vol.80, 641-2.

Bagwell, K. and Staiger, R.W., 1994, "The Sensitivity of Strategic and Corrective R&D Policy in Oligopolistic Industries", *Journal of International Economics*, Vol.36, p.133-50.

Bernstein, J.I. and Nadri, M.I., 1988, "Interindustry R&D Spillovers, Rates of Return, and Production in High-Tech Industries", *American Economic Review (Papers and Proceedings)*, Vol.78, 429-34.

Choi, J.P., 1993, "Cooperative R&D with Product Market Competition", *International Journal of Industrial Organization*, Vol.11, 553-71.

Dixit, A., 1979, "A Model of Duopoly Suggesting a Theory of Entry Barriers", *The Bell Journal of Economics*, Vol.10, p.20-32.

Geroski, P.A., 1993, "Antitrust Policy Towards Co-operative R&D Ventures", *Oxford Review of Economic Policy*, Vol.9, p.58-71.

Henriques, I., 1990, "Cooperative and Noncooperative R&D in Duopoly with Spillovers: Comment", *American Economic Review*, Vol.80, 638-40.

Hinloopen, J., 1994, "Subsidising Cooperative and Non-Cooperative R&D in Duopoly with Spillovers", Working Paper ECO 94/25, *European University Institute*.

Jacquemin, A., 1988, "Cooperative Agreements in R&D and European Anti-Trust Policy", *European Economic Review*, Vol.32, 551-60.

Kamien, M.I. and Zang, I., 1993, "Competing Research Joint Ventures", *Journal of Economics and Management Strategy*, Vol.2, 23-40.

Kamien, M.I., Muller, E. and Zang, I., 1992, "Research Joint Ventures and R&D Cartels", *American Economic Review*, Vol.82, 1293-306.

Katz, M.L. and Ordover, J.A., 1990, "R&D Cooperation and Competition", *Brookings Papers on Economic Activity: Microeconomics*, 137-203.

Mansfield, E., 1985, "How Rapidly Does New Industrial Technology Leak Out?", *Journal of Industrial Economics*, Vol. XXXIV, p.217-23.

Mansfield, E., Rapoport, J., Romeo, A., Wagner, S. and Beardsley, G., 1977, "Social and Private Rates of Return from Industrial Innovations", *Quarterly Journal of Economics*, p.221-40.

Marjit, S., 1991, "Incentives for Cooperative and Non-cooperative R&D in Duopoly", *Economics Letters,* Vol.37, 187-91.

Martin, S., 1985, "Product Differentiation, Welfare, and Market Size", *Econometrics and Economic Theory Paper*, No.8502, Michigan State University.

Martin, S., 1993, *Advanced Industrial Economics*, Basil Blackwell: Oxford.

Martin, S., 1994a, "Private and Social Incentives to form R&D Joint Ventures", *Review of In-dustrial Organization,* Vol.9, p.157-71.

Martin, S., 1994b, "R&D Joint Ventures and Tacit Product Market Collusion", forthcoming, *European Journal of Political Economy*.

Martin, S., 1995, "Public Policies Towards Cooperation in Research and Development: the European Union, Japan, the United States", in Comanor, W., Goto, A. and Waverman, L., (eds.) *Competition in a Global Economy*, Routledge, forthcoming.

Reinganum, J.F., 1989, "The Timing of Innovation: Research, Development, and Diffusion", in Schmalensee, R. and Willig, R.D. (eds.), *Handbook of Industrial Organization,* Amsterdam: North-Holland, Vol.1, p.849-908.

Scherer, F.M., 1979, "The Welfare Economics of Product Variety: An Application to the Ready-to-Eat Cereals Industry", *The Journal of Industrial Economics,* Vol.XXVIII, No.2 (December), p.113-34.

Shapiro, C. and Willig, R.D., 1990, "On the Antitrust Treatment of Production Joint Ventures", *Journal of Economic Perspectives,* Vol.4, p.113-30.

Simpson, R.D. and Vonortas, N.S., 1994, "Cournot Equilibrium with Imperfectly Appropriable R&D", *Journal of Industrial Economics,* Vol.XLII, 79-92.

Singh, N. and Vives, X., 1984, "Price and Quantity Competition in a Differentiated Duopoly", *Rand Journal of Economics,* Vol.15, No.4 (Winter), p.546-54.

Spence, M., 1976, "Product Differentiation and Welfare", *American Economic Review,* Vol.66, No.2 (May), p.407-14.

Spence, M., 1984, "Cost Reduction, Competition, and Industry Performance", *Econometrica,* Vol.52, No.1 (January), p.101-21.

Spencer, B.J. and Brander, J.A., 1983, "International R&D Rivalry and Industrial Strategy", *Review of Economic Studies,* 707-22.

Suzumura, K., 1992, "Cooperative and Noncooperative R&D in an Oligopoly with Spillovers", *American Economic Review,* Vol.82, 1307-20.

Vives, X., 1985, "On the Efficiency of Bertrand and Cournot Equilibria with Product Differentiation", *Journal of Economic Theory*, Vol.36, p.166-75.

Vonortas, N.S., 1994, "Inter-firm Cooperation with Imperfectly Appropriable Research", *International Journal of Industrial Organization*, Vol.12, p.413-35.

Wildman, S.S., 1984, "A Note on Measuring Surplus Attributable to Differentiated Products", *The Journal of Industrial Economics*, Vol. XXXIII, No.1 (September), p.123-32.

Ziss, S., 1994, "Strategic R&D with Spillovers, Collusion and Welfare", *The Journal of Industrial Economics*, Vol. XLII, No.4, p.375-93.

APPENDIX 1 PROOF OF PROPOSITION 1

part (i)

The second order conditions associated with deriving the optimal R&D-subsidies guarantee that the denominators of the respective subsidies are positive. By restrictions on the parameters of the model ($a, A, b, \gamma > 0$, $a > A$, $\theta \in [0,1)$ and $\beta \in [0,1]$) the same is true for the respective numerators.

part (ii)

R&D

Comparing subsidized and non-subsidized R&D under Cournot and Bertrand competition leads to

$$x_{Is}^{C} - x_{I}^{C} = \frac{b\gamma(a-A)(2+\theta)^3}{[b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2]} \times \frac{(3-\theta)\beta+(1-\theta)}{[b\gamma(2+\theta)(4-\theta^2)-2(2-\theta\beta)(1+\beta)]} > 0,$$

$$x_{IIs}^{C} - x_{II}^{C} = \frac{b\gamma(a-A)(1+\beta)(1+\theta)(2+\theta)^2}{[b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2][b\gamma(2+\theta)^2-2(1+\beta)^2]} > 0,$$

$$x_{Is}^{B} - x_{I}^{B} = \frac{b\gamma(a-A)(1+\theta)(2-\theta)^3}{[b\gamma(1+\theta)(2-\theta)^2-(1+\beta)^2(3-2\theta)]} \times \frac{[1+(3+2\theta)\beta]}{[b\gamma(1+\theta)(2-\theta)(4-\theta^2)-2(1+\beta)(2-\theta\beta-\theta^2)]} > 0,$$

$$x_{IIs}^{B} - x_{II}^{B} = \frac{b\gamma(a-A)(1+\beta)}{[b\gamma(2-\theta)^2(1+\theta)-(1+\beta)^2(3-2\theta)]} \times \frac{(1+\theta)(2-\theta)^2}{[b\gamma(1+\theta)(2-\theta)^2-2(1+\beta)^2(1-\theta)]} > 0,$$

$$x_{IIIs}^{C} - x_{III}^{C} = x_{IIIs}^{B} - x_{III}^{B} = \frac{2b\gamma(a-A)(1+\beta)(1+\theta)}{[4b\gamma(1+\theta)-3(1+\beta)^2][2b\gamma(1+\theta)-(1+\beta)^2]} > 0,$$

which hold $\forall \beta \in [0,1]$ and $\forall \theta \in [0,1)$.

<u>Output</u>

Comparing total output for the subsidized and non-subsidized games under Cournot and Bertrand competition leads to

$$Q_{Is}^{C}-Q_{I}^{C} = \frac{2\gamma(a-A)(1+\beta)}{[b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2]} \times \frac{(2+\theta)^2[(1-\theta)+\beta(3-\theta)]}{[b\gamma(2+\theta)(4-\theta^2)-2(2-\theta\beta)(1+\beta)]} > 0,$$

$$Q_{IIs}^{C}-Q_{II}^{C} = \frac{2\gamma(a-A)(1+\beta)^2(1+\theta)(2+\theta)}{[b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2][b\gamma(2+\theta)^2-2(1+\beta)^2]} > 0,$$

$$Q_{Is}^{B}-Q_{I}^{B} = \frac{2\gamma(a-A)(1+\beta)(2-\theta)^2}{[b\gamma(2-\theta)^2(1+\theta)-(3-2\theta)(1+\beta)^2]} \times \frac{[1+\beta(3+2\theta)]}{[b\gamma(1+\theta)(2-\theta)(4-\theta^2)-2(1+\beta)(2-\theta\beta-\theta^2)]} > 0,$$

$$Q_{IIs}^{B}-Q_{II}^{B} = \frac{2\gamma(a-A)(1+\beta)^2}{[b\gamma(2-\theta)^2(1+\theta)-(3-2\theta)(1+\beta)^2]} \times \frac{(2-\theta)}{[b\gamma(1+\theta)(2-\theta)^2-2(1+\beta)^2(1-\theta)]} > 0,$$

$$Q_{IIIs}^{C}-Q_{III}^{C} = Q_{IIIs}^{B}-Q_{III}^{B} = \frac{2\gamma(a-A)(1+\beta)^2}{[4b\gamma(1+\theta)-3(1+\beta)^2][2b\gamma(1+\theta)-(1+\beta)^2]} > 0,$$

which hold $\forall\beta\in[0,1]$ and $\forall\theta\in[0,1)$.

Prices

Comparing prices for the subsidized and non-subsidized games under Cournot and Bertrand competition leads to

$$p_{Is}^{C} - p_{I}^{C} = -\frac{b\gamma(a-A)(2+\theta)^2(1+\theta)}{[b\gamma(2+\theta)(4-\theta^2)-2(2-\theta\beta)(1+\beta)]}$$

$$\times\frac{[(1-\theta)+2(2-\theta)\beta+(3-\theta)\beta^2]}{[b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2]} < 0,$$

$$P_{IIs}^{C} - p_{II}^{C} = -\frac{b\gamma(a-A)(1+\beta)^2(1+\theta)^2(2+\theta)}{[b\gamma(2+\theta)^2-2(1+\beta)^2][b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2]} < 0,$$

$$p_{Is}^{B} - p_{I}^{B} = -\frac{b\gamma(a-A)}{[b\gamma(1+\theta)(2-\theta)(4-\theta^2)-2(1+\beta)(2-\theta\beta-\theta^2)]}$$

$$\times\frac{(1+\beta)(2-\theta)^2(1+\theta)[1+\beta(2\theta+3]}{[b\gamma(2-\theta)^2(1+\theta)-(3-2\theta)(1+\beta)^2]} < 0,$$

$$p_{IIs}^{B} - p_{II}^{B} = -\frac{b\gamma(a-A)}{[b\gamma(1+\theta)(2-\theta)^2-2(1+\beta)^2(1-\theta)]}$$

$$\times\frac{(1+\beta)^2(2-\theta)(1+\theta)}{[b\gamma(2-\theta)^2(1+\theta)-(3-2\theta)(1+\beta)^2]} < 0,$$

$$p_{IIIs}^{C} - p_{III}^{C} = pIIIs^{B} - p_{III}^{B}$$

$$= -\frac{b\gamma(a-A)(1+\beta)^2(1+\theta)}{[4b\gamma(1+\theta)-3(1+\beta)^2][2b\gamma(1+\theta)-(1+\beta)^2]} < 0,$$

which hold $\forall\beta\in[0,1]$ and $\forall\theta\in[0,1)$.

Profits

Comparing profits for the subsidized and non-subsidized games under Cournot and Bertrand competition can only be done analytically for the partial and full cooperation games, the results of which are

$$\pi^C_{IIs} - \pi^C_{II} = -\frac{\gamma(a-A)^2 b\gamma(1+\beta)^2(2+\theta)^2(1+\theta)^2}{2[b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2]^2[b\gamma(2+\theta)^2-2(1+\beta)^2]} < 0,$$

$$\pi^B_{IIs} - \pi^B_{II} = -\frac{\gamma(a-A)^2 b\gamma(1+\beta)^2}{2[b\gamma(2-\theta)^2(1+\theta)-(3-2\theta)(1+\beta)^2]^2}$$

$$\times \frac{(2-\theta)^2(1+\theta)}{[b\gamma(1+\theta)(2-\theta)^2-2(1+\beta)^2(1-\theta)]} < 0,$$

$$\pi^C_{IIIs} - \pi^C_{III} = \pi^B_{IIIs} - \pi^B_{III}$$

$$= -\frac{\gamma(a-A)^2 b\gamma(1+\beta)^2(1+\theta)}{[4b\gamma(1+\theta)-3(1+\beta)^2]^2[2b\gamma(1+\theta)-(1+\beta)^2]} < 0.$$

These inequalities hold for $\forall\beta\in[0,1]$ and $\forall\theta\in[0,1)$. For the two non-cooperative cases we have to rely on numerical simulations. These show that $\pi^C_{Is}-\pi^C_I<0$ and $\pi^B_{Is}-\pi^B_I<0$ for all values any parameter of the model can take, given that second order and stability conditions are satisfied.

Social Welfare

Comparing social welfare for the subsidized and non-subsidized games under Cournot and Bertrand competition leads to

$$W_{Is}^{C} - W_{I}^{C} = \frac{\gamma(a-A)^2 b\gamma(2+\theta)^4}{[b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2]} \times \frac{[(1-\theta)+\beta(3-\theta)]^2}{[b\gamma(2+\theta)(4-\theta^2)-2(2-\theta\beta)(1+\beta)]^2} > 0,$$

$$W_{IIs}^{C} - W_{II}^{C} = \frac{\gamma(a-A)^2 b\gamma(1+\beta)^2(2+\theta)^2(1+\theta)^2}{[b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2][b\gamma(2+\theta)^2-2(1+\beta)^2]^2} > 0,$$

$$W_{Is}^{B} - W_{I}^{B} = \frac{\gamma(a-A)^2 b\gamma(1+\theta)(2-\theta)^2}{[b\gamma(2-\theta)^2(1+\theta)-(3-2\theta)(1+\beta)^2]} \times \frac{[(2+\theta)(3-2\theta)(1+\beta)-2(2-\theta\beta-\theta^2)]^2}{[b\gamma(1+\theta)(2-\theta)(4-\theta^2)-2(1+\beta)(2-\theta\beta-\theta^2)]^2} > 0,$$

$$W_{IIs}^{B} - W_{II}^{B} = \frac{\gamma(a-A)^2}{[b\gamma(2-\theta)^2(1+\theta)-(3-2\theta)(1+\beta)^2]} \times \frac{b\gamma(1+\beta)^2(2-\theta)^2(1+\theta)}{[b\gamma(1+\theta)(2-\theta)^2-2(1+\beta)^2(1-\theta)]^2} > 0,$$

$$W_{IIIs}^{C} - W_{III}^{C} = W_{IIIs}^{B} - W_{III}^{B} = \frac{\gamma(a-A)^2 b\gamma(1+\theta)(1+\beta)^2}{[4b\gamma(1+\theta)-3(1+\beta)^2][2b\gamma(1+\theta)-(1+\beta)^2]^2} > 0,$$

which hold $\forall\beta\in[0,1]$ and $\forall\theta\in[0,1)$.

APPENDIX 2 SOME R&D-LEVELS COMPARED

$$x_I^C - x_I^B = \frac{2b\gamma(a-A)}{[b\gamma(2+\theta)(4-\theta^2)-2(2-\theta\beta)(1+\beta)]}$$

$$\times \frac{(1+\beta)\theta^3(4-\theta^2)}{[b\gamma(1+\theta)(2-\theta)(4-\theta^2)-2(2-\theta\beta-\theta^2)(1+\beta)]} > 0,$$

$$x_{II}^C - x_{II}^B = \frac{4b\gamma(a-A)(1+\beta)\theta^3}{[b\gamma(2+\theta)^2-2(1+\beta)^2][b\gamma(2-\theta)^2(1+\theta)-2(1+\beta)^2(1-\theta)]} > 0,$$

$$x_{Is}^C - x_{Is}^B = x_{IIs}^C - x_{IIs}^B = \frac{b\gamma(a-A)}{[b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2]}$$

$$\times \frac{(1+\beta)\theta^2(\theta^2+2\theta-4)}{[b\gamma(1+\theta)(2-\theta)^2-(1+\beta)^2(3-2\theta)]} < 0,$$

$$x_{Is}^C - x_{IIIs}^C = x_{IIs}^C - x_{IIIs}^C$$

$$= \frac{b\gamma(a-A)(1+\beta)\theta(4+\theta)}{[b\gamma(2+\theta)^2-(3+\theta)(1+\beta)^2][4b\gamma(1+\theta)-3(1+\beta)^2]} > 0,$$

$$x_{Is}^B - x_{IIIs}^B = x_{IIs}^B - x_{IIIs}^B = \frac{b\gamma(a-A)}{[b\gamma(1+\theta)(2-\theta)^2-(1+\beta)^2(3-2\theta)]}$$

$$\times \frac{(1+\beta)(1+\theta)\theta(4-3\theta)}{[4b\gamma(1+\theta)-3(1+\beta)^2]} > 0.$$

$$\frac{\partial x_I^{B}(s)}{\partial \beta} - \frac{\partial x_I^{C}(s)}{\beta}$$

$$= \frac{b(1+\beta)^2}{[b\gamma(2+\theta)(4-\theta^2)2(2-\theta\beta)(1+\beta)]}$$

$$\times \frac{\theta^3(4-\theta^2)}{[b\gamma(1+\theta)(2-\theta)(4-\theta^2)-2(2-\theta\beta-\theta^2)(1+\beta)^2]} > 0,$$

$$\frac{\partial x_{II}^{B}(s)}{\partial \beta} - \frac{\partial x_{II}^{C}(s)}{\partial \beta} = \frac{4b(1+\beta)^2}{[b\gamma(1+\theta)(2-\theta)^2-2(1-\theta)(1+\beta)^2]}$$

$$\times \frac{\theta^3}{[b\gamma(2+\theta)^2-2(1+\beta)^2]} > 0.$$

EUI WORKING PAPERS

EUI Working Papers are published and distributed by the
European University Institute, Florence

Copies can be obtained free of charge
– depending on the availability of stocks – from:

The Publications Officer
European University Institute
Badia Fiesolana
I-50016 San Domenico di Fiesole (FI)
Italy

Please use order form overleaf

Publications of the European University Institute

Department of Economics Working Paper Series

To Department of Economics **WP**
European University Institute
Badia Fiesolana
I-50016 San Domenico di Fiesole (FI)
E-mail: publish@datacomm.iue.it
Italy

From Name . . . .

Address. . . . .

. . . .

. . . .

. . . .

. . . .

(Please print)

❐ Please enter/confirm my name on EUI Economics Dept. Mailing List
❐ Please send me a complete list of EUI Working Papers
❐ Please send me a complete list of EUI book publications
❐ Please send me the EUI brochure Academic Year 1995/96

Please send me the following EUI **ECO** Working Paper(s):

No, Author . . . .
Title: . . . .
No, Author . . . .
Title: . . . .
No, Author . . . .
Title: . . . .
No, Author . . . .
Title: . . . .

Date . . . . Signature . . . .

Working Papers of the Department of Economics Published since 1993

ECO No. 93/1
Carlo GRILLENZONI
Forecasting Unstable and Non-Stationary Time Series

ECO No. 93/2
Carlo GRILLENZONI
Multilinear Models for Nonlinear Time Series

ECO No. 93/3
Ronald M. HARSTAD/Louis PHLIPS
Futures Market Contracting When You Don't Know Who the Optimists Are

ECO No. 93/4
Alan KIRMAN/Louis PHLIPS
Empirical Studies of Product Markets

ECO No. 93/5
Grayham E. MIZON
Empirical Analysis of Time Series: Illustrations with Simulated Data

ECO No. 93/6
Tilman EHRBECK
Optimally Combining Individual Forecasts From Panel Data

ECO NO. 93/7
Víctor GÓMEZ/Agustín MARAVALL
Initializing the Kalman Filter with Incompletely Specified Initial Conditions

ECO No. 93/8
Frederic PALOMINO
Informed Speculation: Small Markets Against Large Markets

ECO NO. 93/9
Stephen MARTIN
Beyond Prices Versus Quantities

ECO No. 93/10
José María LABEAGA/Angel LÓPEZ
A Flexible Demand System and VAT Simulations from Spanish Microdata

ECO No. 93/11
Maozu LU/Grayham E. MIZON
The Encompassing Principle and Specification Tests

ECO No. 93/12
Louis PHLIPS/Peter MØLLGAARD
Oil Stocks as a Squeeze Preventing Mechanism: Is Self-Regulation Possible?

ECO No. 93/13
Pieter HASEKAMP
Disinflation Policy and Credibility: The Role of Conventions

ECO No. 93/14
Louis PHLIPS
Price Leadership and Conscious Parallelism: A Survey

ECO No. 93/15
Agustín MARAVALL
Short-Term Analysis of Macroeconomic Time Series *

ECO No. 93/16
Philip Hans FRANSES/Niels HALDRUP
The Effects of Additive Outliers on Tests for Unit Roots and Cointegration

ECO No. 93/17
Fabio CANOVA/Jane MARRINAN
Predicting Excess Returns in Financial Markets

ECO No. 93/18
Iñigo HERGUERA
Exchange Rate Fluctuations, Market Structure and the Pass-through Relationship

ECO No. 93/19
Agustín MARAVALL
Use and Misuse of Unobserved Components in Economic Forecasting

ECO No. 93/20
Torben HOLVAD/Jens Leth HOUGAARD
Measuring Technical Input Efficiency for Similar Production Units: A Survey of the Non-Parametric Approach

*out of print

ECO No. 93/21
Stephen MARTIN/Louis PHLIPS
Product Differentiation, Market Structure and Exchange Rate Passthrough

ECO No 93/22
F. CANOVA/M. FINN/A. R. PAGAN
Evaluating a Real Business Cycle Model

ECO No 93/23
Fabio CANOVA
Statistical Inference in Calibrated Models

ECO No 93/24
Gilles TEYSSIÈRE
Matching Processes in the Labour Market in Marseilles. An Econometric Study

ECO No 93/25
Fabio CANOVA
Sources and Propagation of International Business Cycles: Common Shocks or Transmission?

ECO No. 93/26
Marco BECHT/Carlos RAMÍREZ
Financial Capitalism in Pre-World War I Germany: The Role of the Universal Banks in the Financing of German Mining Companies 1906-1912

ECO No. 93/27
Isabelle MARET
Two Parametric Models of Demand, Structure of Market Demand from Heterogeneity

ECO No. 93/28
Stephen MARTIN
Vertical Product Differentiation, Intra-industry Trade, and Infant Industry Protection

ECO No. 93/29
J. Humberto LOPEZ
Testing for Unit Roots with the k-th Autocorrelation Coefficient

ECO No. 93/30
Paola VALBONESI
Modelling Interactions Between State and Private Sector in a "Previously" Centrally Planned Economy

ECO No. 93/31
Enrique ALBEROLA ILA/J. Humberto LOPEZ/Vicente ORTS RIOS
An Application of the Kalman Filter to the Spanish Experience in a Target Zone (1989-92)

ECO No. 93/32
Fabio CANOVA/Morten O. RAVN
International Consumption Risk Sharing

ECO No. 93/33
Morten Overgaard RAVN
International Business Cycles: How much can Standard Theory Account for?

ECO No. 93/34
Agustín MARAVALL
Unobserved Components in Economic Time Series *

ECO No. 93/35
Sheila MARNIE/John MICKLEWRIGHT
Poverty in Pre-Reform Uzbekistan: What do Official Data Really Reveal? *

ECO No. 93/36
Torben HOLVAD/Jens Leth HOUGAARD
Measuring Technical Input Efficiency for Similar Production Units: 80 Danish Hospitals

ECO No. 93/37
Grayham E. MIZON
A Simple Message for Autocorrelation Correctors: DON'T

ECO No. 93/38
Barbara BOEHNLEIN
The Impact of Product Differentiation on Collusive Equilibria and Multimarket Contact

ECO No. 93/39
H. Peter MØLLGAARD
Bargaining and Efficiency in a Speculative Forward Market

***

*out of print

*out of print

ECO No. 94/22
Isabelle MARET
Heterogeneity and Dynamics of Temporary Equilibria: Short-Run Versus Long-Run Stability

ECO No. 94/23
Nikolaos GEORGANTZIS
Short-Run and Long-Run Cournot Equilibria in Multiproduct Industries

ECO No. 94/24
Alexander SCHRADER
Vertical Mergers and Market Foreclosure: Comment

ECO No. 94/25
Jeroen HINLOOPEN
Subsidising Cooperative and Non-Cooperative R&D in Duopoly with Spillovers

ECO No. 94/26
Debora DI GIOACCHINO
The Evolution of Cooperation: Robustness to Mistakes and Mutation

ECO No. 94/27
Kristina KOSTIAL
The Role of the Signal-Noise Ratio in Cointegrated Systems

ECO No. 94/28
Agustín MARAVALL/Víctor GÓMEZ
Program SEATS "Signal Extraction in ARIMA Time Series" - Instructions for the User

ECO No. 94/29
Luigi ERMINI
A Discrete-Time Consumption-CAP Model under Durability of Goods, Habit Formation and Temporal Aggregation

ECO No. 94/30
Debora DI GIOACCHINO
Learning to Drink Beer by Mistake

ECO No. 94/31
Víctor GÓMEZ/Agustín MARAVALL
Program TRAMO "Time Series Regression with ARIMA Noise, Missing Observations, and Outliers" - Instructions for the User

ECO No. 94/32
Ákos VALENTINYI
How Financial Development and Inflation may Affect Growth

ECO No. 94/33
Stephen MARTIN
European Community Food Processing Industries

ECO No. 94/34
Agustín MARAVALL/Christophe PLANAS
Estimation Error and the Specification of Unobserved Component Models

ECO No. 94/35
Robbin HERRING
The "Divergent Beliefs" Hypothesis and the "Contract Zone" in Final Offer Arbitration

ECO No. 94/36
Robbin HERRING
Hiring Quality Labour

ECO No. 94/37
Angel J. UBIDE
Is there Consumption Risk Sharing in the EEC?

ECO No. 94/38
Berthold HERRENDORF
Credible Purchases of Credibility Through Exchange Rate Pegging: An Optimal Taxation Framework

ECO No. 94/39
Enrique ALBEROLA ILA
How Long Can a Honeymoon Last? Institutional and Fundamental Beliefs in the Collapse of a Target Zone

ECO No. 94/40
Robert WALDMANN
Inequality, Economic Growth and the Debt Crisis

ECO No. 94/41
John MICKLEWRIGHT/ Gyula NAGY
Flows to and from Insured Unemployment in Hungary

*out of print

ECO No. 94/42
Barbara BOEHNLEIN
The Soda-ash Market in Europe: Collusive and Competitive Equilibria With and Without Foreign Entry

ECO No. 94/43
Hans-Theo NORMANN
Stackelberg Warfare as an Equilibrium Choice in a Game with Reputation Effects

ECO No. 94/44
Giorgio CALZOLARI/Gabriele FIORENTINI
Conditional Heteroskedasticity in Nonlinear Simultaneous Equations

ECO No. 94/45
Frank CRITCHLEY/Paul MARRIOTT/ Mark SALMON
On the Differential Geometry of the Wald Test with Nonlinear Restrictions

ECO No. 94/46
Renzo G. AVESANI/Giampiero M. GALLO/Mark SALMON
On the Evolution of Credibility and Flexible Exchange Rate Target Zones

***

ECO No. 95/1
Paul PEZANIS-CHRISTOU
Experimental Results in Asymmetric Auctions - The 'Low-Ball' Effect

ECO No. 95/2
Jeroen HINLOOPEN/Rien WAGENVOORT
Robust Estimation: An Example

ECO No. 95/3
Giampiero M. GALLO/Barbara PACINI
Risk-related Asymmetries in Foreign Exchange Markets

ECO No. 95/4
Santanu ROY/Rien WAGENVOORT
Risk Preference and Indirect Utility in Portfolio Choice Problems

ECO No. 95/5
Giovanni NERO
Third Package and Noncooperative Collusion in the European Airline Industry

ECO No. 95/6
Renzo G. AVESANI/Giampiero M. GALLO/Mark SALMON
On the Nature of Commitment in Flexible Target Zones and the Measurement of Credibility: The 1993 ERM Crisis

ECO No. 95/7
John MICKLEWRIGHT/Gyula NAGY
Unemployment Insurance and Incentives in Hungary

ECO No. 95/8
Kristina KOSTIAL
The Fully Modified OLS Estimator as a System Estimator: A Monte-Carlo Analysis

ECO No. 95/9
Günther REHME
Redistribution, Wealth Tax Competition and Capital Flight in Growing Economies

ECO No. 95/10
Grayham E. MIZON
Progressive Modelling of Macroeconomic Time Series: The LSE Methodology

ECO No. 95/11
Pierre CAHUC/Hubert KEMPF
Alternative Time Patterns of Decisions and Dynamic Strategic Interactions

ECO No. 95/12
Tito BOERI
Is Job Turnover Countercyclical?

ECO No. 95/13
Luisa ZANFORLIN
Growth Effects from Trade and Technology

ECO No. 95/14
Miguel JIMÉNEZ/Domenico MARCHETTI, jr.
Thick-Market Externalities in U.S. Manufacturing: A Dynamic Study with Panel Data

ECO No. 95/15
Berthold HERRENDORF
Exchange Rate Pegging, Transparency, and Imports of Credibility

*out of print

ECO No. 95/16
Günther REHME
Redistribution, Income cum Investment Subsidy Tax Competition and Capital Flight in Growing Economies

ECO No. 95/17
Tito BOERI/Stefano SCARPETTA
Regional Dimensions of Unemployment in Central and Eastern Europe and Social Barriers to Restructuring

ECO No. 95/18
Bernhard WINKLER
Reputation for EMU - An Economic Defence of the Maastricht Criteria

ECO No. 95/19
Ed HOPKINS
Learning, Matching and Aggregation

ECO No. 95/20
Dorte VERNER
Can the Variables in an Extended Solow Model be Treated as Exogenous? Learning from International Comparisons Across Decades

ECO No. 95/21
Enrique ALBEROLA-ILA
Optimal Exchange Rate Targets and Macroeconomic Stabilization

ECO No. 95/22
Robert WALDMANN
Predicting the Signs of Forecast Errors

ECO No. 95/23
Robert WALDMANN
The Infant Mortality Rate is Higher where the Rich are Richer

ECO No. 95/24
Michael J. ARTIS/Zenon G. KONTOLEMIS/Denise R. OSBORN
Classical Business Cycles for G7 and European Countries

ECO No. 95/25
Jeroen HINLOOPEN/Charles VAN MARREWIJK
On the Limits and Possibilities of the Principle of Minimum Differentiation

ECO No. 95/26
Jeroen HINLOOPEN
Cooperative R&D Versus R&D-Subsidies: Cournot and Bertrand Duopolies

*out of print